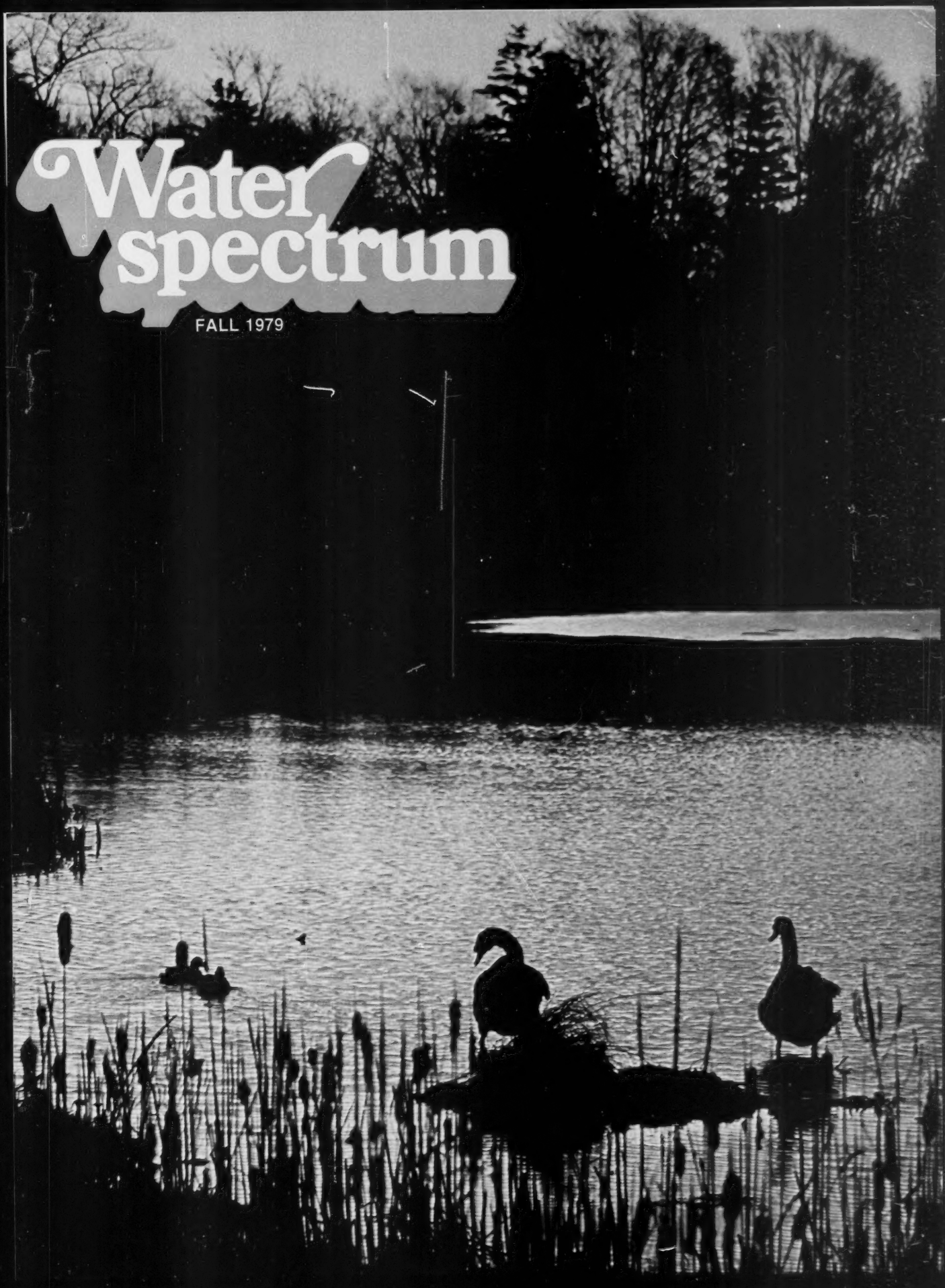
Water spectrum

FALL 1979



Water spectrum

Published Quarterly | Vol. 11, No. 4 | Fall 1979

Secretary of the Army Clifford L. Alexander, Jr.
Chief of Engineers Lt. Gen. J. W. Morris
Director of Civil Works Maj. Gen. E. R. Heiberg III
Editor Bob Norton
Assistant Editor Vacant
Staff Writer Vacant
Editorial Assistant Francine Griffin

Thermal Discharge Research
by John Cairns, Jr., Donald S. Cherry and Stephan R. Larrick
1

The Geothermal Option
by Robert Mallis
9

Fifty Years On The Ohio
by William J. Hull
15

Trouble In Paradise
by John C. Fine
24

National Waterways Study
by Arlene L. Dietz
26

Regional Ground Water Systems Analysis
by G. D. Bennett
36

Susitna Survey: Concern For The Land
by Weldon Opp & Allan Wylie
43

Comments on topics in this publication are invited. Send to:
Editor, Water Spectrum
U.S. Army Corps of Engineers
Water Resources Support Center (WRSC)
Fort Belvoir, VA. 22060
Letters to authors % Editor will be forwarded.

Use of funds for printing this quarterly publication was approved by the Director of the Office of Management and Budget through June 30, 1982.

A major purpose of this publication is to serve as a written forum for the open discussion of issues and choices in resolving water resource problems. Views and conclusions expressed or implied do not necessarily reflect the position of the Corps of Engineers.

Subscription rate is $5.50 per year; $1.40 additional for foreign mailing. Price of a single copy is $1.40. Order directly from Superintendent of Documents, Government Printing Office, Washington, D.C. 20402.

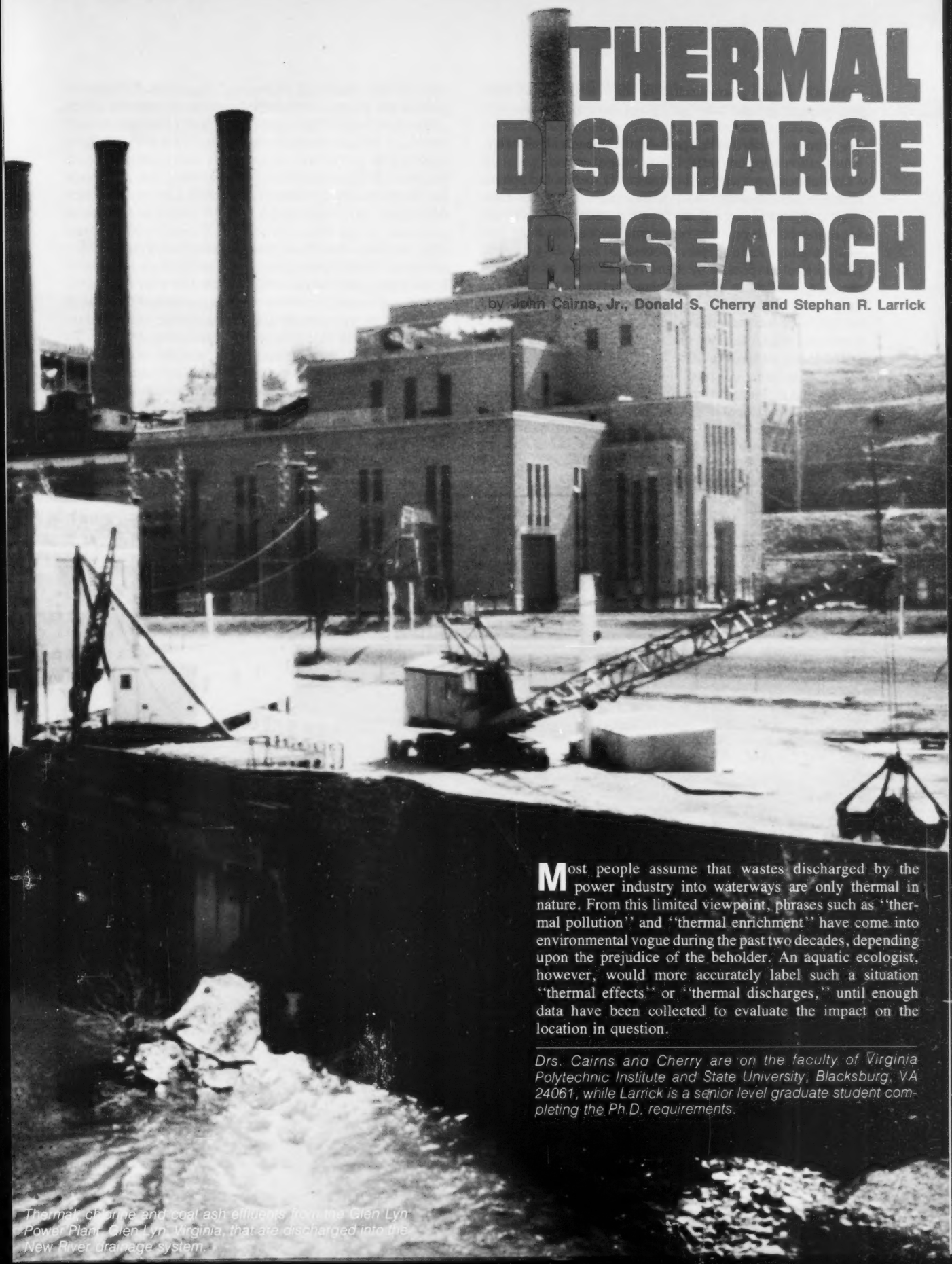
This issue developed by Publications & Training Office, WRSC

Address changes: Please attach old address label to request for changes.

COVER: "Far in a western brookland
That bred me long ago,
The poplars stand and tremble
By pools I used to know."—A.E. Housman
(Photo by Tom Pantages)

THERMAL DISCHARGE RESEARCH

by John Cairns, Jr., Donald S. Cherry and Stephan R. Larrick



Most people assume that wastes discharged by the power industry into waterways are only thermal in nature. From this limited viewpoint, phrases such as "thermal pollution" and "thermal enrichment" have come into environmental vogue during the past two decades, depending upon the prejudice of the beholder. An aquatic ecologist, however, would more accurately label such a situation "thermal effects" or "thermal discharges," until enough data have been collected to evaluate the impact on the location in question.

Drs. Cairns and Cherry are on the faculty of Virginia Polytechnic Institute and State University, Blacksburg, VA 24061, while Larrick is a senior level graduate student completing the Ph.D. requirements.

Thermal, chlorine and coal ash effluents from the Glen Lyn Power Plant, Glen Lyn, Virginia, that are discharged into the New River drainage system.

Overall, power plant discharges may be classified into three general groups:

- Heated waste water;
- Intermittent chlorination (periodic treatment with chlorine for antifouling purposes);
- Coal ash effluent with associated heavy metals and potentially toxic elements.

An additional category involves the entrainment or impingement of fish or other organisms forced into the plant from the pump station intake process.

Behavioral responses by fish, in the form of field or laboratory preference and avoidance studies to thermal discharges, have been proposed as a newer approach to evaluate the first of these potential impacts. Avoidance by fish of chlorinated wastes has been more recently investigated and related to intermittent toxicity tests, to compare avoidance thresholds to lethal concentrations. The impact of coal ash releases into drainage systems from settling ponds upon fish, aquatic invertebrate, macrophyte and microbial populations, has only received sparse attention—with most published studies currently carried out at the Savannah River Project (SRP) near Aiken, South Carolina.

Besides the behavioral and ecological impacts of these potential perturbations, an additional way to evaluate these effects is to add measured concentrations of these agents to developing communities housed in artificial streams located at the power plant. The responses to these controlled, monitored effluents in model streams can be evaluated by determining structural or functional changes in these communities through time. A more detailed description of the methods for evaluating power plant discharges is presented.

Thermal, Chlorine and Coal Ash Discharges

Power plants are required to meet specific regulations concerning the effluents that are discharged into aquatic systems. These requirements are site-specific and dependent upon state and Federal statutes. For thermal discharges, the U.S. Environmental Protection Agency (EPA) has established specific demonstrations to obtain a variance for closed-cycle cooling (*Federal Register,* Vol. 39, No. 196, Oct. 8, 1974).

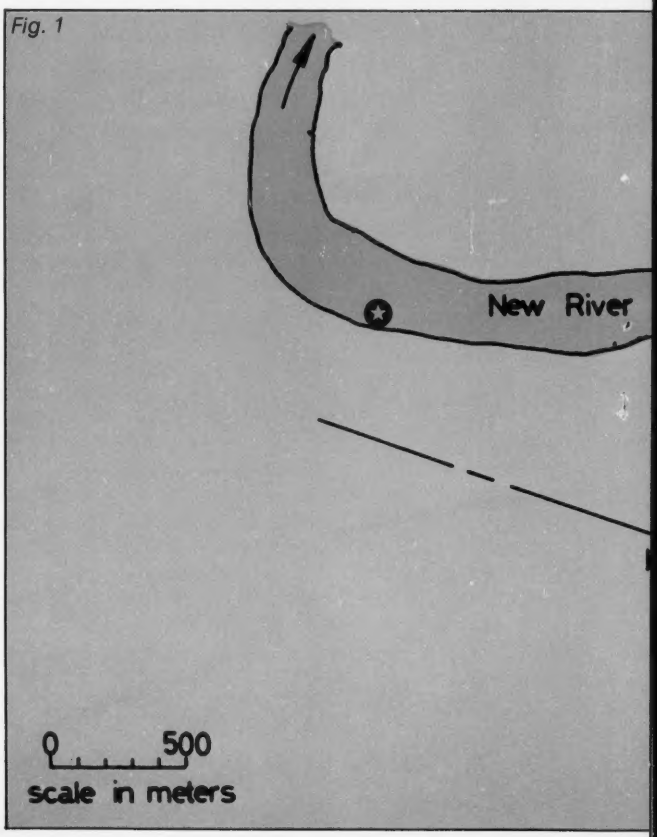
In applying for a National Pollution Discharge Elimination Systems (NPDES) permit, Public Law 92-500, Section 316(a) has provided the electrical power industry the opportunity to demonstrate, to the relevant permitting authority, that the effluent limitation proposed is more stringent than necessary to assure the protection and propagation of a balanced, indigenous population of shellfish, fish and wildlife in and on the aquatic system being addressed. The use of preference and avoidance data in a Type 2 (use of the EPA's draft water temperature criteria that conditions at the site would protect important representative species) situation demonstration is one of three approaches in which water-temperature criteria from site-specific data are used to demonstrate that there are no adverse effects. Use of a Type 1 (on-site data to demonstrate the absence of prior appreciable harm to the biological community) or Type 3 (combination of biological and engineering data to demonstrate no adverse effects) demonstration is also applicable depending upon data availability.

Intermittent chlorination by the power industry has been used in the control of biofouling organisms. In order to prevent the buildup of bacterial and fungal growths in the condenser tubes, which reduces the inner tube diameter and efficiency of heat transfer, chlorine doses are released intermittently (e.g., usually three times daily for 30-minute intervals) to retard this buildup. In addition, the invasion of the Asiatic clam (*Corbicula fluminea*) into American waterways since 1938 has added a new dimension to biofouling problems. At the Glen Lyn Plant in Virginia's New River, clam densities (on a per square meter basis) in the river sediments of the thermal discharge have increased from zero in 1975 to approximately 18 in October 1976. By September 1977, they reached 1020 per square meter and as high as 11,500 by February 1978. Unfortunately, they defy control from intermittent chlorination by "clamming up."

This behavioral mechanism is simply a protective mechanism to shield their vulnerable meaty tissue from the potentially stressful, chlorinated environment by tightly closing their shells and reopening them for filter-feeding purposes after the biocide has passed. Current biocidal practices have been unsuccessful, and the potential of attachment into condenser tubes, lodging there and causing tube deterioration, has been documented. Discharge permit limitations, as determined from bioassays of fish, have been established by the EPA in the formulation of NPDES permits (Public Law 92-500, Section 402(b) as later amended by the Clean Water Act, Public Law 95-217).

Behavioral avoidance responses by fish offer a new approach in the evaluation of the potential impact from inter-

Fig. 1



mittent chlorination. If fish can demonstrate an ability to detect chlorinated residuals and react by an avoidance mechanism, then current discharge limitations may be considered as too restrictive. Since mortality of fish in chlorinated thermal plumes has not been a normal, documented procedure, fish have shown the ability to actively detect a potentially lethal, chlorinated condition and swim out of these areas to portions of the heated water where chlorine levels are lower.

The potential impact of coal ash effluent released from holding ponds into aquatic drainage systems has received relatively minor attention. Current restrictions, established from P.L. 92-500, are placed upon the sulfur content in coal (1.5 percent), suspended solid concentration in heavy ash effluent (30 ppm), and ranges in pH (6-9). Field studies assessing the dilution of coal ash in settling basins have shown that mortality to aquatic biota may occur by siltation from coal ash particles discharged from inefficiently operated settling basins. Additional lethal conditions have resulted from acidic or basic pH effluents (e.g., ranges below pH 5.0 or greater than 10.0), or from the elemental constituents (e.g., copper, zinc, cadmium, arsenic, selenium) associated with coal ash. These subsequent discharges into receiving waters need more attention.

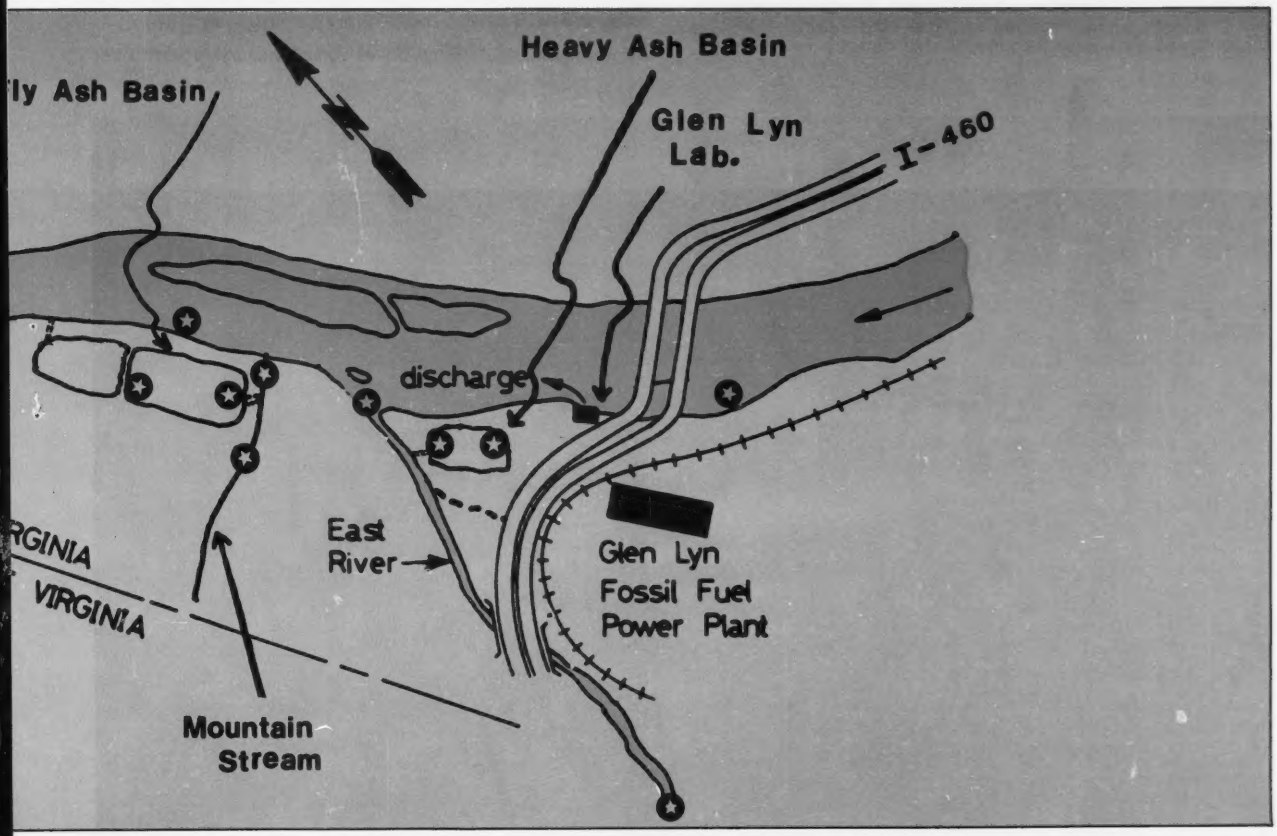
Research is lacking on the toxic effects of coal ash relative to those lethal mechanisms of siltation or elemental contamination. *In situ* bioassays and population sampling in holding ponds may provide further information about the siltation, pH, and elemental problems associated with coal ash effects.

Impingement-Entrainment

The loss of organisms to cooling water intakes has a definite impact on aquatic biota residing near power facilities. When water is pumped into the plant, larval fish pass through traveling screens that remove debris, and are then subjected to physical impact, changes in water pressure, thermal shock and biocide toxemia (mortality from intermittent chlorination practices) during the entrainment process. Impingement occurs to the larger organisms, when they are lodged on the screening devices and suffer mortality from starvation, exhaustion, asphyxiation or desiccation. Periodic sampling of the screens and the water column, using plankton nets, can provide information concerning the potential impact of entrainment and impingement upon the resident fish life. Assessment of this impact is evaluated in accordance with the provisions of Section 316(b) of P.L. 92-500.

Experimental Approaches

Discharges of waste heat, chlorinated residuals, and coal ash effluents from the Glen Lyn Power Plant in Virginia are represented in Fig. 1. Waste heat and chlorine are discharged simultaneously into the New and East Rivers. Ash effluent is segregated into two settling basins—a heavy ash and a fly ash system. River water is used to wash the burned coal ash residues from the power plant into the settling basins. After settling occurs in the basins, the excess water is released or discharged back into the river below the plant. The former system releases effluent into the East River, which then flows into the New River. Fly ash is discharged below the East



River into a mountain stream that drains into the New River. Several sampling stations have been established above, below and within these mixing zones to evaluate their effect upon the resident fish populations. The mixing zones represent regions of river water which contain a greater density of coal ash particles and/or heated water than normally found in uninfluenced regions of the river. As these effluents continually mix downstream, the area of mixing is sufficiently diluted to eventually become completely dissipated.

Fig. 2 Schematic representation of the temperature preference unit for fish.

Temperature Preference Unit

The unit described in Fig. 2 was developed from a fish hatchery trough 363 cm long, 36 cm wide, and 20 cm deep. A series of 12 250-watt infrared lamps, set at increasing intensity from the end where cold water was introduced, heated the trough from underneath. The lamps are equipped by rheostats to increase the wattage toward the hotter end to facilitate a higher temperature, and temperature gradients as wide as 20°C were obtained in a water column of approximately 3 cm. This gradient expansion is facilitated by adding cold water from a constant temperature bath which lowers the temperature sufficiently at the cooler end. A series of 21 equally-spaced thermistors, connected to a temperature readout, was used to measure the temperature regime and fish location. Preferred temperatures were obtained after one to three hours following fish acclimation to the trough, when movement was restricted or confined to a narrow temperature interval. (Movement is restricted by the wide temperature gradient formed in that fish are experimentally forced to move within an area where the hot and cold extremes are undesirable, while the middle portion of the trough contains a more desirable temperature selection regime.)

The apparatus allowed for the testing of single individuals or small groups (4-8) of schooling juveniles. The simplicity of this unit was a basic advantage that provided fish interaction in a relatively consistent temperature gradient, without the need to contend with additional variables from complex environmental structures.

Temperature and Chlorine Avoidance System

The avoidance unit in Fig. 3 was versatile as a temperature or

Fig. 3 Temperature and chlorine avoidance unit with temperature-controlled water baths, chlorine pumping system, and closed-circuit television monitor.

chlorine avoidance facility, or as a combination of both variables. River water was pumped into two 64-liter water baths, which maintained water at a constant temperature and supplied two linear troughs. Water from each bath entered at the opposite ends of each trough and emptied at center drains. For temperature avoidance studies, the water temperature in one bath was continually raised. This produced a higher temperature in half of each trough, while the opposite side was maintained at the acclimation temperature for the experimental fish. Temperatures were raised to the point at which a species spent significantly less time in the heated side prior to the time of temperature elevation.

Chlorine avoidances were carried out in a similar manner, in that one water bath was dosed with chlorine and maintained by a carboy containing chlorine solution which entered half of each trough. Repeated dosing in the bath and carboy formed a sequence of doubling chlorine increments or exposures in the heated side of the troughs, until an avoidance reaction was observed.

Separate experiments were monitored wherein half of each trough was raised to the preferred temperature of a fish species. This resulted in the attraction of fish into the heated side. Following this response, the heated side was chlorinated as previously described. Fish movement and residence time (e.g., time spent by fish in the experimentally treated or stressed side of the trough) were observed on a closed circuit television camera and monitoring system. This type of design was similar to the chlorinated, heated discharge produced from the power plant, which formed a steep gradient at the junction of treated effluent with uninfluenced river water.

In order to assess the response of fish to the intermittent chlorination doses discharged into the New River drainage system, several sampling locations (Stations 1-3) were established (Fig. 4). The dissipation of chlorinated residuals was monitored through the discharge canal for a distance of 375 meters downstream. Water samples were measured immediately in the field, using a portable amperometric titrator.

At Station 2, the substrate of the East River was relatively smooth and favored seining for fish. This area was characterized by a sharp gradient into which the mixing zone was highly influenced by elevated temperature and chlorinated residuals that dissipated rapidly downstream. Uninfluenced river water was immediately above the confluence of the discharge canal and East River at Station 2. Fish were subjected to an immediate, sharp mixing zone when moving down the river.

This situation was "duplicated" in the laboratory temperature and chlorine avoidance experiments (as discussed earlier in Fig. 3), by allowing treated water to flow into the avoidance troughs at opposite ends and emptying at the center drains. Consequently, avoidance thresholds from the laboratory trials could be compared to field avoidances to further substantiate fish avoidance responses to potentially lethal conditions.

Coal Ash Bioassays

Most information about the effect of coal ash perturbation has been based on field data; laboratory data have not been reported. Coal ash toxicity has been reported in *in situ* experiments where organisms have been held in cages in the ash drainage system.

In our present investigations, laboratory bioassays may be carried out through two approaches: One in a conventional

Fig. 4 Research site and field sampling stations at the Glen Lyn Power Plant, Virginia.

static test where coal ash has settled out, and the other in a circulating tank where ash particulates are continuously suspended by circulation (Fig. 5).

From the coal ash studies that have been generated, it is difficult to partition, or attempt to selectively separate, the lethal influences of coal ash—which include siltation of benthic organisms—from particulate sedimentation, aquatic acidity after pH reduction, or exposure to the associated heavy metals and toxic elements.

Impingement-Entrainment Designs

Above the raceway, where water and debris are released from the traveling screens of the power plant, two sampling baskets were attached to a permanent frame (Fig. 6). Baskets were lowered by an electric winch into the raceway to collect the debris and impinged fish that were washed from the screens. This procedure allowed greater volumes of debris to be sampled for extended time intervals.

Entrained larval fish were sampled in the discharge canal using a rectangular plankton net that was attached to a system of weights (Fig. 7). A flow meter, attached at the opening of the net, facilitated the calculation of the water volume sampled. This procedure assured that all samples were taken from the same locaton for every sampling period.

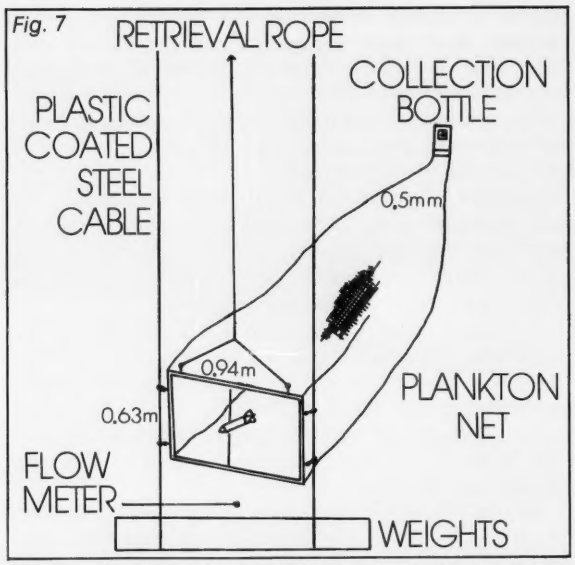


Diagram of the fish entrainment process, which uses a combination of plankton net, collection bottle, and flow meter attached to weighted cables in the river.

Fig. 5 The bioassay unit for suspended coal ash effluent.

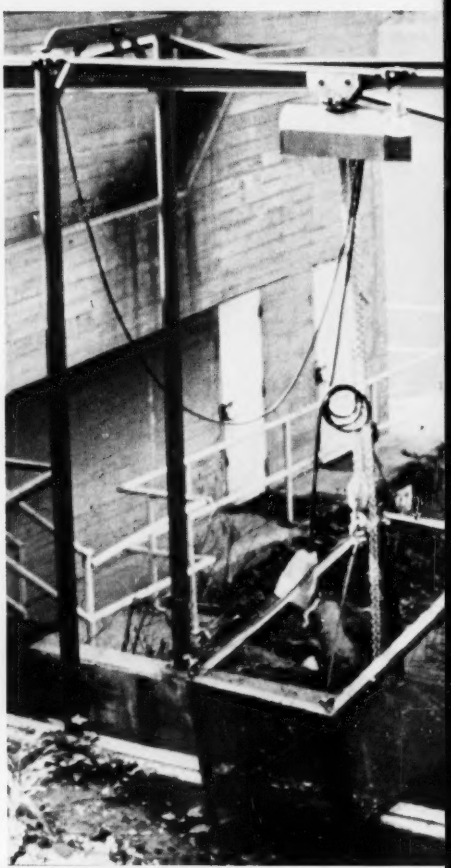


Fig. 6 The electric-powered impingement sampling system.

Assessment By Artificial Streams

The use of artificial streams, located at the power plant site and continually flushed with river water, provides a practical means of evaluating power plant effluents. Structural components and functional units of selected biotic communities, that might be influenced by energy production discharges, may be evaluated in these streams. Structural components include the quantity, quality or composition of species (such as numbers per unit area or density), and pattern of organization of biotic populations. Functional units relate to the rate processes (rates of energy flow, nutrient cycling and ecological regulation) of the system.

These systems have been flexible or versatile by allowing for rapid colonization, relatively simple application or exposure to perturbation, and evaluation of the effects in relatively brief periods of time. Since it is extremely difficult to monitor and control the variables inherent in a large river, the attempt here was to simulate the river condition as it is pumped into a small, more easily controlled unit or microcosm.

River water was pumped into the upper end, flowed over a mixing box which received selected toxicants, and then flowed through the stream, exiting at the opposite end on a once-through cycle. After colonization by resident biota (e.g., periphyton, snails, Asiatic clams), or from the introduction of selected organisms (e.g., crayfish, foragers or herbivorous fish species), specific increments of power plant effluents may be added to evaluate the loss of specific species (structure) or the change in their general physiological interaction (function) (Fig. 8).

Mechanisms of coal ash toxicity may be more effectively evaluated by using a combination of structural and functional approaches. Stream length may also facilitate an avoidance reaction in mobile organisms if the effluent gradient is wide enough to allow for stressed and unstressed regions. By reducing the artificial stream flow, a gradation or mixing zone effect can be obtained in a few meters of space that may be related to the overall effect in miles of zonation influence that occurs in the river.

Most of the temperature, chlorine, heavy metal and toxic element studies have been carried out in laboratories with little reference to the discharge site. Biological assessment of industrial waste discharges under partly controlled conditions in artificial streams or at a field laboratory offers several advantages not found in traditional studies: (1) the use of natural river water for holding and testing aquatic organisms, without accounting for loss or changes in water quality from shipment; (2) an improved simulation of natural

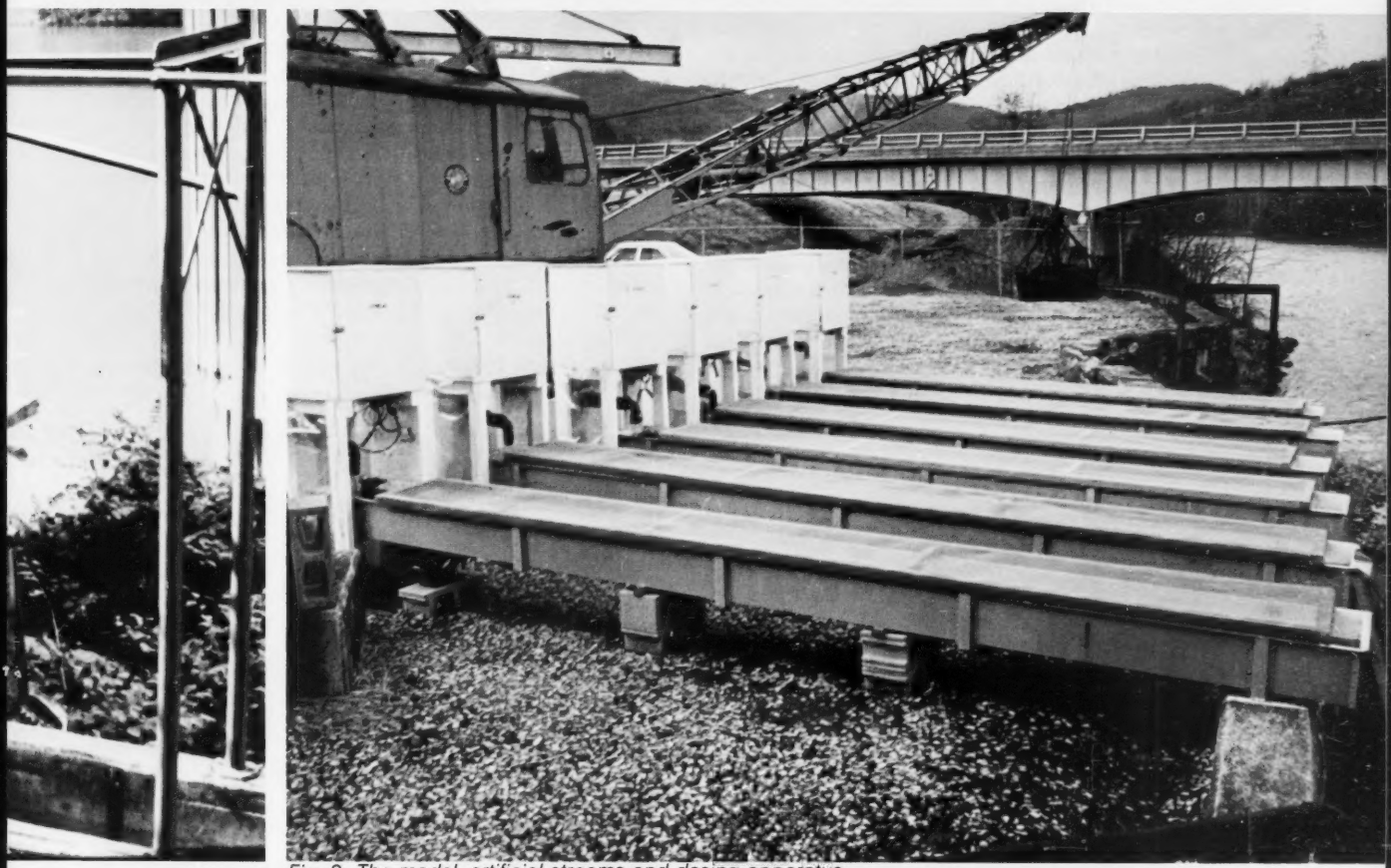


Fig. 8 The model, artificial streams and dosing apparatus.

or waste water effects at the site; (3) use of indigenous flora or fauna from "natural" colonization in artificial streams; (4) proximity of collecting areas and holding or acclimating endemic fish species at a constant temperature, without any significant lapsed time in transportation between collection and placement in the laboratory facility; and, (5) the facilities for evaluating ecological effects of selected populations exposed to power plant discharges under a more or less semi-controlled field-laboratory arrangement.

Effluents from power plant production have not been collectively evaluated for any one population or community at any specific power plant site. Of the four major categories of power plant operations and discharges, thermal effects upon aquatic organisms have been most thoroughly researched. Toxicity to chlorinated residuals has received recent attention, especially in the application of NPDES permits. Impingement-entrainment studies have been emphasized even more recently. The potential impact of coal ash discharges has been studied only in a single system (SRP), and more data need to be generated in order to partition or simplify the complexities of the effluent relative to toxic effects.

The use and advantages of a site-specific field laboratory and adjacent artificial stream system offer much promise in the improvement of environmental research capabilities in assessing the role of power plant discharges upon aquatic ecosystems. By using this site-specific approach, the Glen Lyn Plant has obtained an NPDES permit to continue the discharge of the heated effluent since no appreciable harm to the fish populations in the New River was observed in the 316(a) and (b) variance procedures. The financial gain to the company, and ultimately to the public consumer, was that millions of dollars were saved by not building expensive cooling towers to reduce the heated water influence into this aquatic environment.

In summary, the risks are high concerning the necessity to maintain environmental integrity along with the need to minimize escalating costs by the power industry in the discharge of maximum acceptable discharge limitations. One may equate this "scenario" to a poker game in which all the chips are on the table (e.g., chlorine toxicity, coal ash siltation-pH-and elemental effects, thermal discharges, and impingement-entrainment consequences). (Fig.9)

The effects are, in most cases, a composite of several influences that may be synergistic in which the influence of one may be enhanced by the presence of another. By studying all the defense mechanisms inherent in the biotic community, as indicated by the "aces in back pockets" (or under gill flaps, etc.), the potential impact may be minimized by the built-in mechanisms inherent in the biology of the resident populations present. The suspected abiotic effects resulting from effluents altering the river water quality may be offset or compensated by several biological mechanisms, which include preference-avoidance mechanisms of fish, migration by fish or other organisms to spawning areas uninfluenced by these discharges, possible acclimation or adjustment to these impacts, resistance, or behavioral mechanisms by clams,—all of which are responses to thermal pollution.

On the opposite side of the coin or poker chip, the response may be enrichment, as in the case of thermal discharges, where fish prefer or select the heated effluents. In the aquatic ecological research trends currently being accepted, the overall picture must be evaluated, which includes the effects of abiotic (physical and chemical) water quality conditions upon the whole ecosystem of producers (algae and rooted plants), decomposers (bacteria and fungi), and consumers (microinvertebrates, macroinvertebrates, and fish).

In a similar analogy, the scientific community needs to investigate the complete scope of power plant discharge activities as has and is being done by the American Electric Power Service Corporation at the Glen Lyn Plant in Virginia, and at other plants concerning thermal, chlorine and coal ash effluents, and impingement-entrainment consequences. This combined effort should provide a better assessment in the preservation of the environmental quality, and hopefully, will be carried out more thoroughly elsewhere.

The authors wish to acknowledge that their research effort at the Glen Lyn field laboratory has been supported by the American Electric Power Service Corporation, Canton, Ohio, and studies of the artificial streams system by the U.S. Department of Energy in Washington. ■

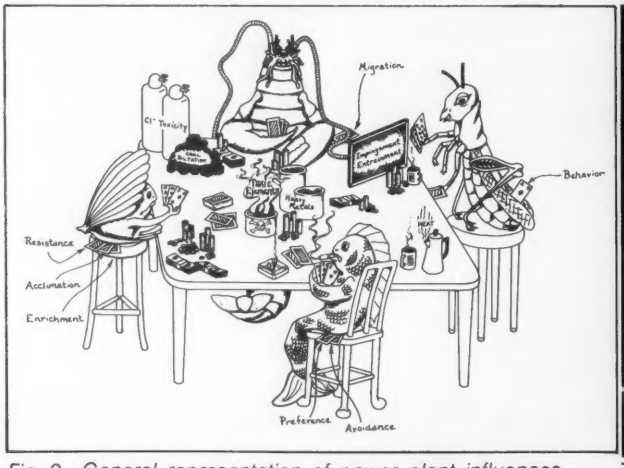


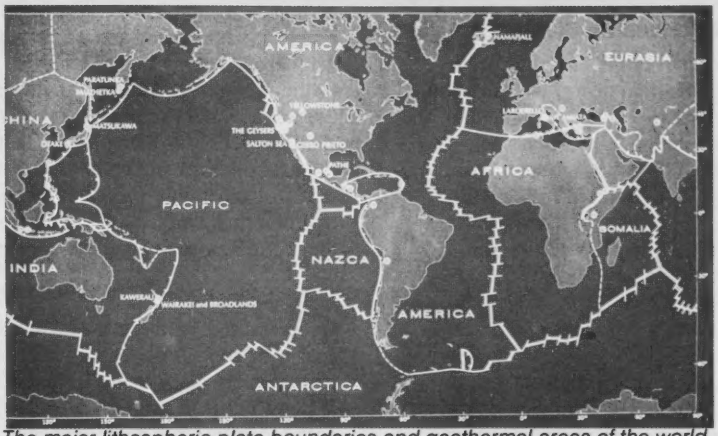
Fig. 9 General representation of power plant influences and responses by aquatic biota in receiving systems.

The Asiatic clam (Corbicula fluminea), *showing its density in river sediments influenced by thermal discharge.*

the geothermal option

by **Robert Mallis**

Man has long been aware that temperatures within the earth increase with depth. Measurements of temperatures in deep mines and drill holes indicate the average rate of increase in the upper 10 kilometers is approximately 20° to 25°C per kilometer. Furthermore, various geophysical and geochemical data indicate that temperatures continue to increase below the deepest drill holes. According to thermal models of the earth, temperatures at the base of the continental crust, a depth of 25 to 50 kilometers, range from 200° to 1000°C. At the center of the earth the temperature is probably between 3500° to 4500°C.



The major lithospheric plate boundaries and geothermal areas of the world (from Muffler). Heavy double lines are spreading ridges where new material is being added; heavy lines with barbs are subduction zones where crustal material is being moved downward; single solid lines are transform faults where two plates are moving laterally to one another. Uncertain boundaries are shown by dotted lines.

Thus, the earth contains a very large quantity of heat—or geothermal energy. This heat is generated by several natural processes within the earth. These include: (1) decay of long-lived radioactive elements, particularly uranium, thorium, and potassium; 2) chemical differentiation of an originally homogeneous earth into the present core, mantle, and crust; 3) dissipation of rotational energy as the earth's rotation rate decreases with time; and 4) conversion of kinetic energy to heat as the earth was accreted from primordial matter about 4.5 billion years ago. Of these four processes, radioactive decay is probably the most important.

Although the earth contains an immense amount of geothermal energy, most of this heat is far too deeply buried to be used efficiently by man. The deepest drill holes reach less than 10 kilometers, and, even though it may be possible at some future time to drill deeper, it is unlikely that heat will be extracted economically from such great depths. Commercial utilization of geothermal energy in the foreseeable future will probably be restricted to heat at depths less than 10 kilometers.

Mr. Mallis is with the U.S. Geological Survey's Office of Geochemistry and Geophysics, Menlo Park, California 94025.

Even when all of the geothermal energy below 10 kilometers is eliminated from consideration, there is still a very large quantity of heat left in the upper crust. D.E. White of the U.S. Geological Survey estimated the amount of heat above surface temperature stored in the upper ten kilometers of the earth to be approximately 3 x 10^{26} calories.[1] This is probably more than 2000 times the heat represented by the total coal reserves of the world. Most of the heat, however, is distributed too diffusely throughout the upper 10 kilometers to be useful. The average heat content of each gram of rock in the outer 10 kilometers of the earth is only 0.3 percent of the heat obtained from the combustion of one gram of coal and is less than 0.01 percent of the heat equivalent of fissionable uranium and thorium contained in one gram of average granite. Consequently, most of the heat in the outer 10 kilometers cannot be considered a resource.

At certain locations in the crust, however, geologic processes have created anomalous concentrations of heat that cause the geothermal gradient to be above normal. At these locations, temperatures may be high enough and at an accessible depth to permit economic extraction of geothermal energy.

Location of Geothermal Resources

Geothermal resources are the result of two continuing processes within the earth: (1) conductive flow of heat from the interior toward the surface; and, (2) movement of molten rock from the interior toward the surface. Both of these processes can be related to the modern principle of plate tectonics (movement of the earth's crust). The central precept of plate tectonics holds that the outer part of the earth is fragmented into several large, rigid plates which move relative to one another at rates of several centimeters per year.

[1]White, D.E., 1965, *Geothermal Energy:* U.S. Geological Survey Circular 519.

The regions where these plates come into contact with each other are characterized by earthquakes, volcanic activity, and high heat flow. The heat flow rate at plate margins may be 1.5 to 5 times greater than the worldwide average of about 60 milliwatts per square meter. The driving force of plate movement is thought to be convective circulation within the earth's mantle. At plate margins, molten rock moves into the upper segment of the crust and either is extruded on the surface as volcanic rock or becomes lodged a few kilometers below the surface to form a magma reservoir.

Hydrothermal Convection Systems

In regions where the upper part of the crust has been heated above normal by either high heat flow, intrusion of magma, or both, and the rock is permeable enough to allow substantial water circulation, a hydrothermal convection system may exist. In such a system, cool meteoric water percolates down from the surface, is heated, expands, and then buoyantly rises in a manner very similar to a pot of simmering soup. The driving force is gravity, effective because of the density difference between hot and cold water. The principal mode of heat transfer within a hydrothermal system is the convective circulation of water.

Experience gained from drill exploration of hydrothermal convection systems around the world indicates that in most systems liquid water is the dominant, pressure-controlling fluid. Even though the temperature at depth may be well above the surface boiling point, pressure from the weight of overlying fluid increases the temperature point at which boiling would commence and the water remains in a liquid state. Wells drilled into such systems usually produce a mixture of water and steam at the wellhead. As the hot, liquid water rises in the well, the pressure decreases and some of the water, usually 10 to 30 percent, flashes to steam. In a few hydrothermal systems, however, wells produce saturated or superheated steam with no water. In such systems, the in-hole pressure of shut-in wells increases only slightly with depth. The pressure increase is equivalent to a column of steam, much less than the increase in an equivalent column of water. These systems are called vapor-dominated because pressures are controlled by steam rather than by liquid water. Two examples of the relatively rare vapor-dominated systems are the geothermal fields at Larderello in north central Italy and The Geysers in northern California.

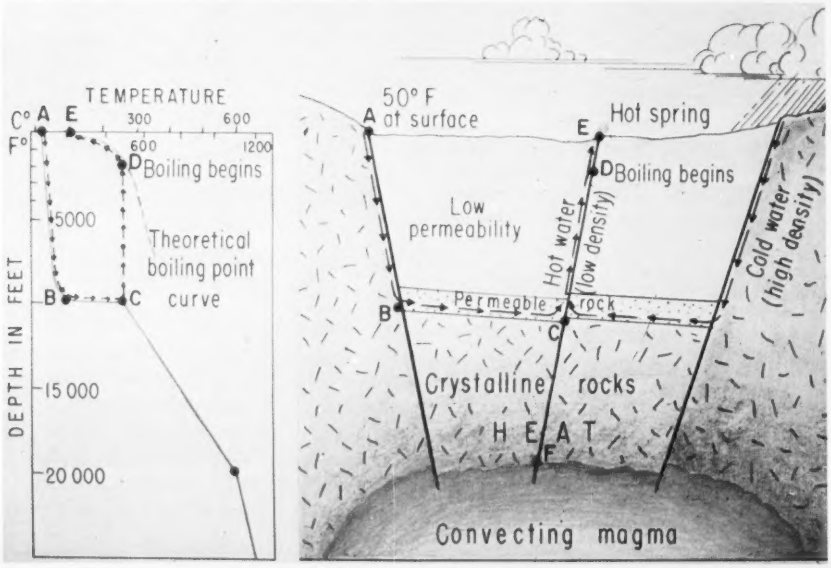
Active hydrothermal systems are manifested as thermal springs in many places on the earth's surface. Man probably began using these easily accessible sources of geothermal energy before recorded history—for healing, heating, cooking, and enjoyment. By the beginning of the twentieth century, natural hot water from springs and shallow wells was being used in several parts of the world to heat buildings and hothouses. Because they are by far the most accessible source of geothermal heat, hydrothermal convection systems account for nearly all of the world's present geothermal energy production.

Geopressured Systems

Geopressured geothermal systems are another potential source of geothermal energy that has been attracting increased attention in the United States. Geopressured systems occur in geologically young structural basins filled with sediments that were deposited as the basins subsided.

Unlike hydrothermal systems, the fluid found in a geopressured reservoir is not water that percolates from the surface. The water in these systems was trapped in the sediments at the time of deposition. This connate water cannot readily escape to the surface because it is trapped by overlying impermeable rock formations. The water remains in the sediments, confined at pressures that can approach the pressure exerted by the overlying rock.

Although there is no anomalous, deep-heat source such as in hydrothermal systems, temperatures in geopressured



Schematic model of a hot-water geothermal system (modified from White). Curve 1 shows the boiling point of pure water under pressure exerted by a column of liquid water everywhere at boiling, assuming water level at ground surface. Dissolved salts shift the curve to the right; dissolved gases shift the curve to the left. Curve 2 shows the ground temperature profile of a typical hot-water system.

reservoirs are elevated due to the insulating effect of the water-rich geopressured sediments which trap the earth's normal heat flow.

A well known geopressured system occurs along the Gulf Coast of the United States where extensive oil drilling has incidentally discovered and delineated large reservoirs of geopressured water at temperatures up to 273°C. The geothermal energy contained in these reservoirs is augmented by methane dissolved in the geopressured water. Thus far, no energy has been produced from any geopressured sytem and the feasibility of utilizing this resource has not been demonstrated.

Hot Dry Rock

Another potential source of geothermal energy is "hot dry rock." This term is applied to rock that is hot but does not have sufficient permeability and porosity to sustain convective circulation. Wells drilled into hot dry rock would not produce water or steam. Such conditions exist throughout much of the crust, particularly in the deeper parts.

The technical feasibility of using hot dry rock is being investigated at the Los Alamos Scientific Laboratory (LASL) in New Mexico. The program proposed by LASL involves drilling to temperatures of 200° to 300°C and fracturing the rock by pumping water into the hole under high pressure. Under this methodology, once a fracture is produced a second hole is drilled to intersect the fracture. Cold water is then pumped into the first hole, heated at depth, and finally withdrawn through the second hole. At the present time, a hydraulically fractured reservoir in low permeability rock at about 185°C has been created and flow tested for 75 days at an energy extraction rate of about five thermal megawatts. Plans are underway to enlarge this to 50 thermal megawatts.

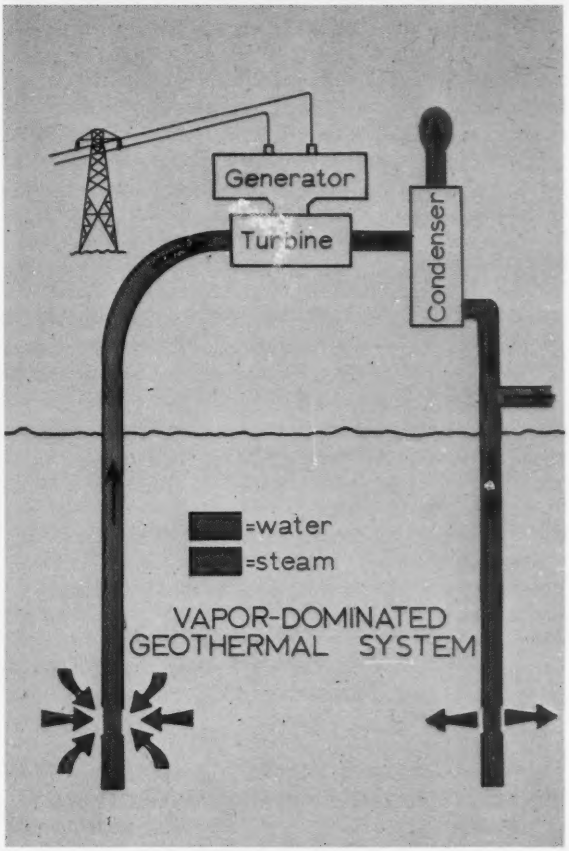
Analysis by LASL of the technical and economic feasibility of using hot dry rock as an energy source suggests grounds for guarded optimism for the production of electricity in areas of the United States with temperature gradients of 40°C per kilometer or greater. Although this concept may someday be economically and technically feasible it is presently experimental and many problems must be solved before hot dry rock becomes a geothermal resource.

Uses and Limitations of Geothermal Energy

Geothermal energy can either be used directly as heat or, if the resource is hot enough, it can be converted to electrical energy. In recent years, direct use of geothermal energy has taken a back seat, while the research thrust has been on geothermal electric power generation. The constraint here, however, is that only the highest temperature geothermal resources can be used to generate electricity. The major part of the world's geothermal resources are too cool for electrical power but are ideal for space heating, agricultural applications, industrial process heat, and even air-conditioning. Since a very large proportion of the world's energy consumption is in the form of heat, use of geothermal energy for this purpose could save a large quantity of oil and gas that otherwise would be burned for heat.

A fundamental constraint on direct use of geothermal energy is the nature and distribution of the resource. It is just not practical to transport heat more than a few miles at most. Direct use of geothermal energy, therefore, must take place near its source.

In this century the use of geothermal energy for generation of electricity has received increased attention. Electricity was first produced from geothermal energy in 1904 at Larderello, Italy. Generating capacity at this vapor-dominated field has been gradually expanded over the years and today the field produces about 400 megawatts of electrical power. It is not coincidence that the Larderello field was the first source of geothermal electric power. Vapor-dominated systems are nearly ideal for electrical generation since they produce only dry steam along with minor amounts of certain other gases.



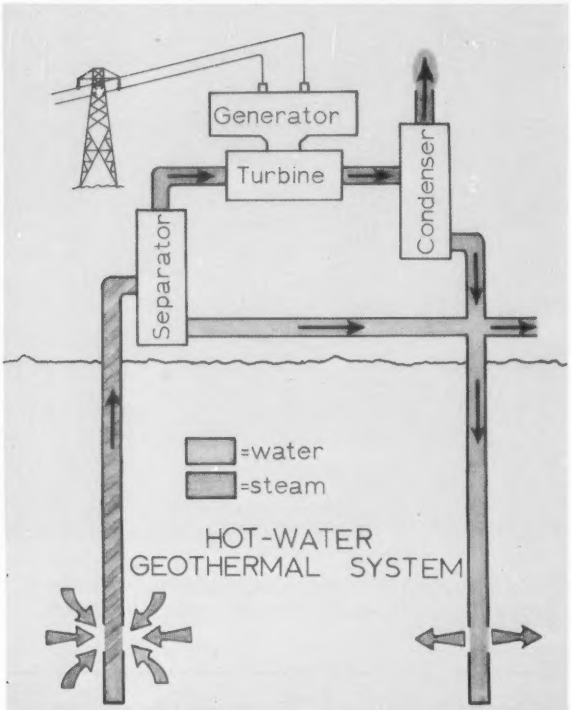
Schematic diagram of electrical production using steam from a vapor-dominated geothermal system (from Sato, Crocker, and Muffler.)

This steam can be piped directly from the well to a turbogenerator. The largest geothermal power facility in the world, located at The Geysers in northern California, is a vapor-dominated system and is also presently the only geothermal power facility in the United States.

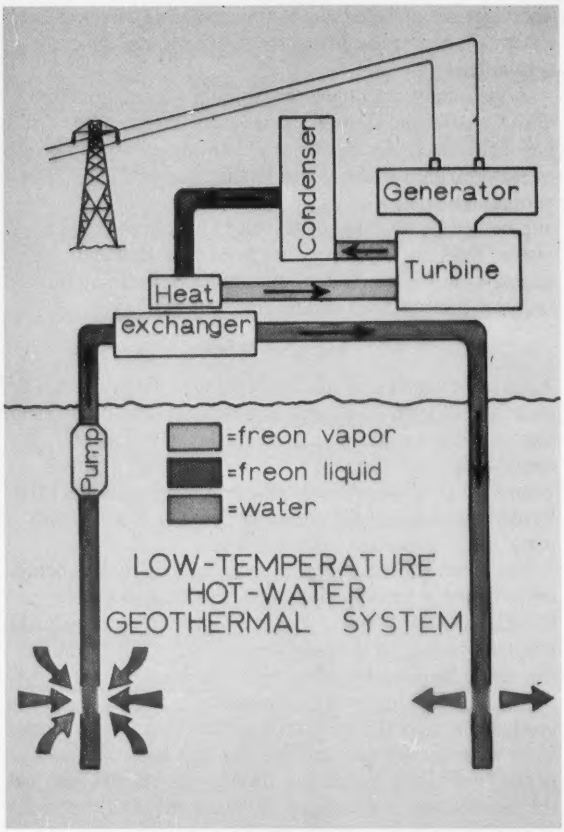
Unfortunately, vapor-dominated systems are very rare phenomena and only a few are known to exist.

Hot-water hydrothermal systems are much more common than the vapor-dominated systems. Hot-water systems with reservoir temperatures higher than about 180°C can be used for electric power generation by allowing a portion of the hot water to flash to steam. After flashing, the water is removed in a separator and the steam is passed through a turbine. One disadvantage of this method is that a large amount of waste heat and water is produced along with the steam. This water, in many cases, contains unacceptably high levels of dissolved solids for surface disposal. The most accepted method in the United States for disposing of this waste water is to reinject it using a separate well for disposal purposes. Reinjection not only prevents contamination of surface waters but also conserves reservoir heat that would otherwise be lost.

Hot-water systems with reservoir temperatures less than 180°C generally do not produce enough flash steam to operate a normal power plant. Electric power generation from moderate temperature geothermal resources has been proposed using a binary cycle power plant. In such a plant, the geothermal fluid is passed through a heat exchanger. A secondary fluid which has a lower boiling point than water, such as Freon, is heated in the exchanger, vaporized, and used to drive a turbine. No fluid is lost at the surface since all of the geothermal water is reinjected after passing through the heat exchanger.



Schematic diagram of electrical production using steam from a hot-water geothermal system (from Sato, Crocker, and Muffler.)



Schematic diagram of electrical production from a low-temperature hot-water system using the binary method where a heat exchanger is used to heat a low-boiling point fluid such as freon (from Sato, Crocker, and Muffler.)

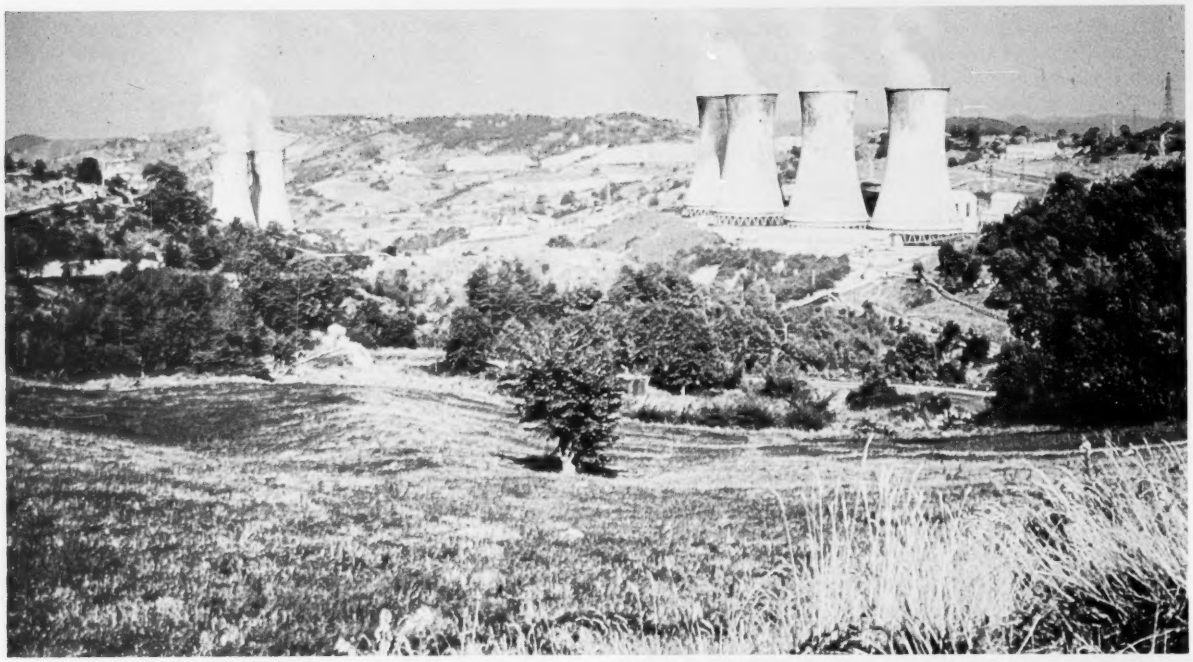
To date, all geothermal electricity production has been from hydrothermal systems. Future use of other sources of geothermal energy such as geopressured systems and hot dry rock await development of suitable technology and economic conditions.

Use of geothermal energy for electric power generation is subject to a number of technical, economic, and environmental considerations. These include:

- Scaling and corrosion—Geothermal fluids generally contain relatively large amounts of dissolved solids such as calcium carbonate and silica. Production of these fluids may promote physical and chemical changes leading to scaling and corrosion of wells and pipelines. These materials also have a potentially harmful effect on turbine blades and heat exchangers. Reinjection of spent geothermal water may lead to deposition of solids in the reservoir, thereby decreasing permeability and porosity.
- Reservoir lifespan and size—The useful lifespan of a geothermal reservoir cannot be determined with reasonable certainty. This is due to a lack of reliable information about the true size of the mass of rock and water forming a reservoir, the nature of its immediate heat source, the rate of heat transfer from this source to the reservoir, and the effects of changed fluid circulation due to increased drawoff.
- Environmental effects—Although geothermal power production does not have the adverse environmental effects equated with fossil fuel or nuclear power plants (geothermal power is a relatively "clean" source), potential environmental problems do exist.

Power plants and cooling towers at The Geysers geothermal field, northern California. The present generating capacity of this vapor-dominated geothermal system is more than 500 megawatts, enough to supply most of the electrical needs for a city the size of San Francisco.

Geothermal plants, because of their low efficiency, produce a large percentage of waste heat. As was mentioned earlier, geothermal fluids may contain undesirable concentrations of dissolved salts and heavy metals. Reinjection of spent geothermal water into fault zones may induce seismic activity. Furthermore, withdrawal of large quantities of water can cause ground subsidence. Some other, lesser, environmental impacts include noise, visual clutter from steam lines, gaseous emissions such as hydrogen sulfide, well casing failure resulting in blowouts, and pollution of adjacent land, estuaries and other water bodies by highly saline brines.



Larderello geothermal field, Italy. This vapor-dominated hydrothermal system was first used for electricity generation in 1904. Today the field produces about 400 megawatts of electricity.

Conclusions

Geothermal energy will probably never provide more than a small percentage of man's total energy needs. Nevertheless, it can become an important alternate energy source, especially in areas with an abundance of geothermal resources. The ultimate extent of geothermal energy use depends upon a number of interrelated factors. These include:

- The cost of competing energy sources;
- Improvements in the technology of drilling and geothermal fluid utilization;
- Use of low-temperature geothermal resources for non-electric applications; and,
- Development of a method to economically fracture hot-dry rock and extract the heat.

As the cost of energy continues to rise, geothermal energy will become an increasingly attractive alternate energy resource. ■

The information contained in this article is largely a synthesis of previous papers on geothermal energy written by L. J. P. Muffler and D. E. White of the U.S. Geological Survey. I want especially to thank L. J. P. Muffler for his review and helpful comments.

*Table 1. World Geothermal Generating Capacity, 1978, in Megawatts**

Country	Constructed		Planned	
	Vapor-dominated	Hot-water	Vapor-dominated	Hot-water
Chile				30
El Salvador		60		35
Iceland		32.5		30
Indonesia			30	
Italy	417.6		64	
Japan	47	124		50
Kenya				15
Mexico		75		105
New Zealand		202		100
Nicaragua				105
Philippines		3		435
Taiwan		0.6		5
Turkey		0.5		15
USA	502		622	275
USSR		5		23

**unpublished data from D. E. White*

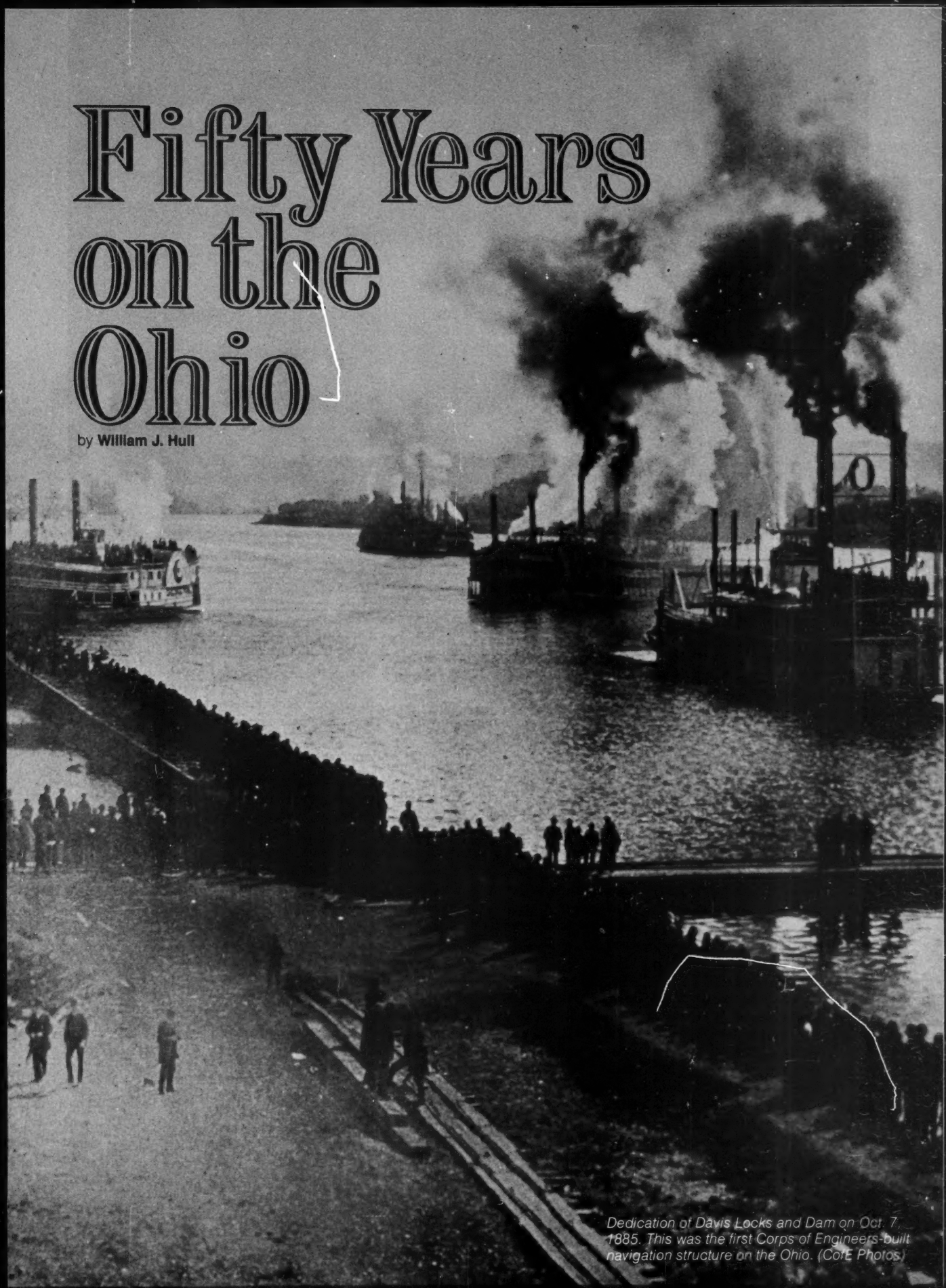
Just prior to press time, the U.S. Geological Survey announced that the United States could tap as much energy from underground heat sources as current U.S. oil consumption would equal in 162 years.

The Survey said the upper six miles of the earth's crust beneath the U.S. contains usable heat energy equivalent to 1.2 trillion barrels of oil. The two types of energy are not always interchangeable, however, the report cautioned.

In addition to the geothermal energy being produced at The Geysers in California mentioned in this article, hot water from underground sources has been used for some heating requirements in Boise, Idaho, and Klamath Falls, Oregon.

Fifty Years on the Ohio

by **William J. Hull**



Dedication of Davis Locks and Dam on Oct. 7, 1885. This was the first Corps of Engineers-built navigation structure on the Ohio. (CofE Photos)

Power plants located along the Ohio in West Virginia because of the availability of water and river-borne coal.

Fifty years ago this fall, President Herbert Hoover made a packet boat trip from Pittsburgh to Cairo, Illinois, to dedicate the newly completed Ohio River Navigation System. The System provided, by means of a series of 50 low-lift dams in conjunction with 100′ x 600′ locks, a dependable navigation channel with a minimum stable depth of nine feet for the entire 981 miles of the river.

The President's theme was simple and clear, and as history has shown, profoundly true. He advocated improvements to our inland river system, he said, "Because it will contribute to the wealth and economic progress of every section of the nation." Speaking at Louisville in October 1929, he said he encouraged "capital investments" in the nation's waterway system, "because they are not local in their benefits. They are universal in promoting the prosperity of the nation."

The dramatic engineering and construction work marked a major milestone in the forward movement of America.

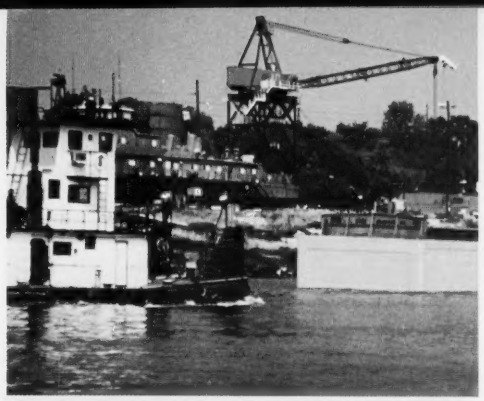
This year, as Ohio River towns and cities and many thousands of citizens join in celebrating that memorable event, we can take pride also in the completion of 13 of the high-lift modern structures of the 19 planned for the replacement of the old system. We can look forward with confidence to consummation of the Modernization Program well before the turn of the century. Just as we recall the enormous role of the 1929 model of the river in providing the transportation base for technological advance in river boats and barges and for wide-ranging economic growth, so we can rest our hopes for a still brighter future upon the best potential of the new system for encouraging new plant investment in basic industry and associated expansion of employment opportunities.

Already we have a "New Ohio." It is busier than ever, moving in modern, high-powered, integrated tows enormous volumes of coal, petroleum, chemicals, grain, sand and gravel, iron and steel and other basic commodities, which represent—in combination with traffic carried on the tributaries—more than one-half of all intercity freight in the Ohio River Basin.

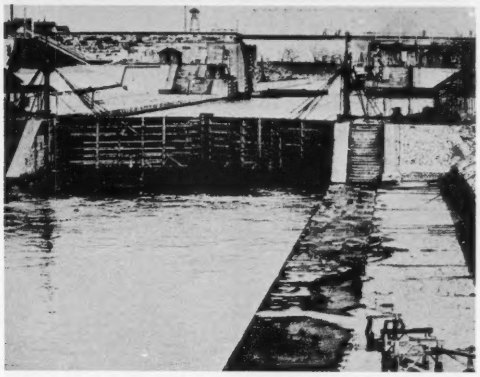
The energy efficiency of river transportation and its capability for moving large volumes of bulk commodities and liquids at low cost over long distances promises an even more vital role to the people of the Valley in the future and an even greater contribution to the achievement of primary national objectives in energy, restraint of inflation, increased productivity and an improved balance of international trade, than the old river promised in its romantic glory days.

The nation's waterways have been in the

Mr. Hull is the president of the Ohio Valley Improvement Association.



Jeff-Boat Shipyards at Jeffersonville, Indiana, manufactures barges and tow boats and launches them directly into the Ohio River. During World War II, many amphibious craft (such as LSTs) were built here and taken down the Ohio to the Mississippi and the Gulf of Mexico.



The Louisville and Portland Canal was privately built in the 1820s to allow river traffic to bypass the three mile rapids of the Falls of the Ohio at Louisville. The U.S. took over operation in 1874.

A Corps of Engineers maneuver boat tends the huge wooden wickets that made up the dams on the old Ohio Navigation System.

forefront of constructive thinking and planning by leaders in government, industry and agriculture since our earliest days as a nation.

The framers of our Constitution, Presidents such as Washington, Jefferson, Madison, John Quincy Adams, Jackson and Lincoln, and statesmen such as Webster, Clay and Calhoun, all understood that a waterway system developed and maintained by the Federal Government was essential to the growth and prosperity of the fledgling nation.

The broad philosophy of these leaders and the lessons of history were not lost on those who conceived and advanced the original Ohio River Project, nor on their spiritual descendants who have devoted themselves to the Modernization Program—recognizing that efficient water transportation is a key element in contending with our most pressing national economic problems.

In this 50th anniversary year, a brief review of the history of the Ohio River Navigation System should improve our understanding of the enduring values of inland navigation and strengthen our resolve to move the Ohio River Modernization Program ahead to early completion. We may, indeed, venture to hope that the Ohio River story may help to enlighten those who would cast aside the traditional wisdom and terminate waterway development programs in a vain search for some never-never-land of rustic simplicity.

In the early history of the American Continent, the bitter struggle for control of the American empire between the French and British centered largely on 981 miles of the Ohio River. When the French were no longer able to control the river, the result was a foregone conclusion: the British would be victorious. When the British, in turn, were unable to prevent the young United States from using the river to colonize the Ohio Valley, their dream of empire on the North American Continent was lost.

The work of the U.S. Army Engineers in the Ohio Valley started in 1824, when Congress appropriated funds for improving navigation over sandbars in the Ohio River, and for removing snags from the Ohio and Mississippi Rivers. The first major improvement on the Ohio River was the construction of a lock and canal around the falls of the Ohio at Louisville—by the Louisville and Portland Canal Company under charter by the Commonwealth of Kentucky. The lock and canal were opened to navigation in 1830, and operation of the project was taken over by the United States in 1874.

The first lock and dam constructed by the U.S. Army Engineers—at Davis Island, about five miles below Pittsburgh—was completed in 1885. Between 1885 and 1910, Congress provided for the construction of 12 more navigation locks and dams. By 1910, the value

Steam-powered paddlewheelers served as tow boats on the Ohio in the early years. Following World War II, diesel power took over.

of the waterway was increasingly recognized, and the government authorized the construction of 54 locks and dams to provide a navigable depth of nine feet from Pittsburgh to the mouth of the Ohio River. By 1929, additions and modifications of the original plan resulted in a navigation system of 50 locks and dams.

Economic forecasts for the nine-foot system saw tonnages moving on the river ultimately reaching a total of 13 million tons a year. In 1929 the Ohio carried almost 23 million tons of freight and in 1979 it will likely move nearly 160 million tons.

The growth in waterborne traffic put an unmanageable demand on the systems of locks. In 1954 the Modernization Program of the Ohio began. It was a plan to replace the original 50 locks and dams (by that date reduced to 46) with 19 larger and more efficient structures.

The Modernization is almost complete although there have been some changes. The 19th facility—Mound City Locks and Dam near Cairo—is being restudied by the Corps of Engineers to see if rehabilitation of two of the original structures might do the job as well.

This October one of the last of the modernization structures—the Smithland Locks and Dam on the lower Ohio River near Paducah, Kentucky—will be dedicated.

Over the long history of the Federal policy concerning the nation's rivers and harbors Congress has based its decisions to authorize and fund navigation projects on the grounds (a) that the benefits of such projects, when economically justified, are widespread in general and (b) improvement of the nation's rivers and harbors is a highly effective instrument for achievement of major national policy objectives.

A look at the history of these programs demonstrates their remarkable versatility in serving a wide variety of public purposes. This is particularly true of the Ohio River.

In our early years, the river systems' improvements served to unify a nation threatened by the splintering tendencies of its remote frontiers. They facilitated westward expansion and they helped to defeat sectionalism with its internal trade barriers and discriminatory impositions upon commerce.

By the 1870s these improvements were a vital factor in restraining rates charged by the railroads which were so exorbitant as to obstruct economic development of regions and communities.

In more recent years, waterways' improvement has been effectively applied to stimulate the economies of underdeveloped regions of the country through improved market outlets and access to raw material sources, to strengthen the farm economy through cheaper distribution and to strengthen the national security by provision of mass transport of fuels and critical materials and by encouragement of industrial dispersion.

In this period of unemployment, combined with soaring inflation and complicated by

The Ohio River ends at Cairo, Illinois, and adds its waters to the Mississippi River.

The process of "double locking" emerged in the late 1940s as tows got too big for the old 600 foot locks. The locking time grew to almost two hours and caused traffic delays as long as three days.

intensified environmental concern, a wisely designed program to provide our country with a first class waterway transportation system contributes materially to the solution of these pressing national problems.

The Ohio River Modernization Program has provided convincing evidence of the critically important part such a program can play in reducing both unemployment and the rate of inflation while contributing significantly to the achievement of national environmental goals.

The basic fact is that the influence of water transportation on the economy and quality of life of the Ohio River Basin is widely diffused. Electric utilities headquartered in inland cities such as Canton and Columbus, Ohio, operate power plants on the Ohio River for reliance on waterborne coal and receive the energy so produced into their service areas via high-voltage transmission lines. Trucks also distribute waterborne gasoline and fuel oil over broad areas of the Ohio River Basin. Continued development of public river ports, notably in Indiana, Kentucky, and Ohio, with their railroad and highway connections, spreads the benefits of improved river transportation even more widely. This is particularly important for farm marketing and fertilizer supplies.

Industrial expansion based upon modernization of the Ohio River navigation facilities has been and is a vital factor in the achievement of higher levels of employment. The Ohio Valley Improvement Association has for many years conducted a period survey to determine the extent of major investment in new and expanded industrial plants in the counties bordering the Ohio River and its navigable tributaries. The latest survey found that for the 1950-1976 period, over $5.64 billion has been invested in such facilities in those counties. A separate survey made a few years ago by OVIA revealed that from 1965 to 1970 new plants, whose location in the Ohio Valley was governed by the availability of water transportation, created new employment for over 45,000 workers with annual payrolls at the time exceeding $447 million.

Taking into account the additional income to investors and the respending impact on local trade and service activities, it is evident that the employment and incomes which were generated by these plants would be much higher today.

The multiplication of the benefits, resulting from investments stimulated by availability of low-cost water transportation, is graphically evidenced by the results of a study of the effects of waterborne commerce on the Louisville, Kentucky Metropolitan Area, conducted by the Urban Studies Center of the University of Louisville. The study showed a combined direct and indirect economic impact of waterborne commerce on the area of some $588 million in wages and salaries in 1972. Studies currently underway by the State of Ohio as to feasibility of public port development at Cincinnati, Portsmouth, and

Pittsburgh's Golden Triangle, where the Monongahela and Allegheny Rivers meet to form the Ohio River.

other Ohio River cities should show similar encouraging results.

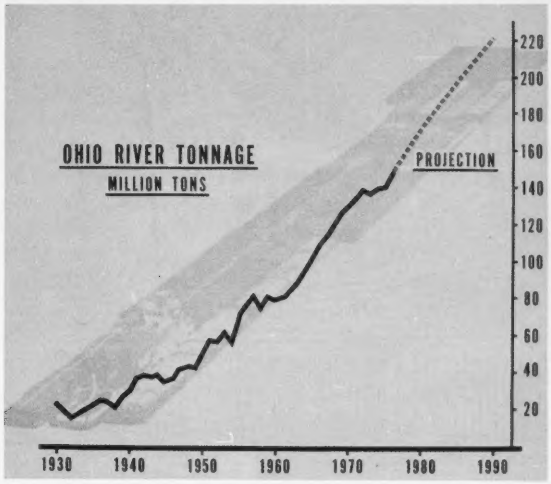
Higher employment in the Ohio Basin is associated with restraint of inflation, resolving in principle the otherwise stubborn dilemma of unemployment versus inflation as supposedly alternative evils. The cost of transportation by water is only about one-third the average of comparable large volume railroad haulage of bulk commodities and a much smaller fraction of the cost of highway transportation. The restraint of inflation induced by water transportation is especially pervasive. Because of the basic character of the industries heavily relying on waterway transportation—steel, aluminum, chemicals, coal mining and preparation, electric power, petroleum refining and building materials production—the infrastructure of the economy—their costs of production enter directly or indirectly into the final price of virtually every product offered at the retail counter.

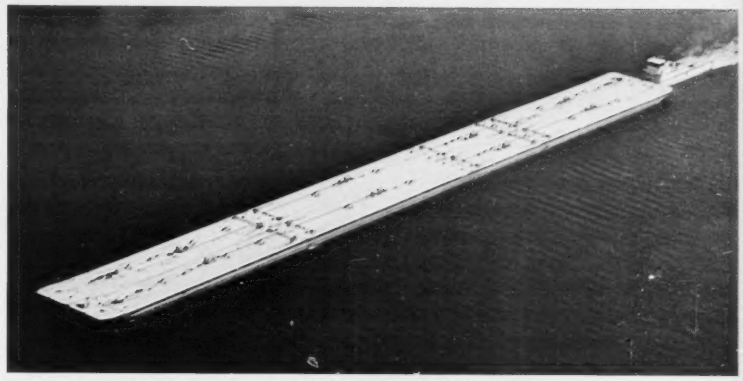
The fuel adjustment rate formula which converts changes in fuel costs at the power plants into changes in power rates at homes, offices and factories has recently received public attention as fuel costs and associated power rates have risen. Electric power stations on the banks of the Ohio and its navigable tributaries produce about 10 percent of all electric energy in the country. Most of this energy is produced from waterborne coal. Modern navigation facilities completed over the past 15 years, greatly reducing transportation costs, are exercising an important favorable influence on the power rate levels.

Cost restraint associated with many billions of dollars of new plant construction and modernization in the Ohio Basin is a substantial counter-inflationary influence. In a mature industrial region such as this, the higher prices of raw materials and fuels and the greatly increased wage standards of recent years would have exercised a much stronger impact on prices of finished goods in the absence of substantially increased output per man-hour of work. In achieving this increase in output, new and modernized plant design has played a major role. Referring, again, to the $56.4 billion investment reported by the OVIA survey. These investments were made in the region only because the executives of the respective firms found to their satisfaction that the Ohio Basin locations provided the greatest productivity and the lowest cost of the locational alternatives available to them.

In many sectors of government activity, public expenditure exercises a depressing influence on private investment by inducing enlarged government competition with the private sector for capital funds. This adverse influence on private investment tends to retard the expansion of low-cost supply of energy forms of other commodities and services. But, in the case of navigation improvements in the

The "temporary" 1200 foot lock at Lock and Dam 52 was built by the Corps' Louisville District in 1969 to ease river traffic jams. It reduced waiting and locking time from as much as 72 hours to less than one hour. The facility is just downstream from Paducah, Kentucky.





Modern tow boats and barges are built to suit the cargo. The large barges carry petroleum products more safely than any other mode of transportation. One barge holds nearly seven million gallons.

Ohio Basin, the effect is rather that of conserving investment and enhancing its productivity.

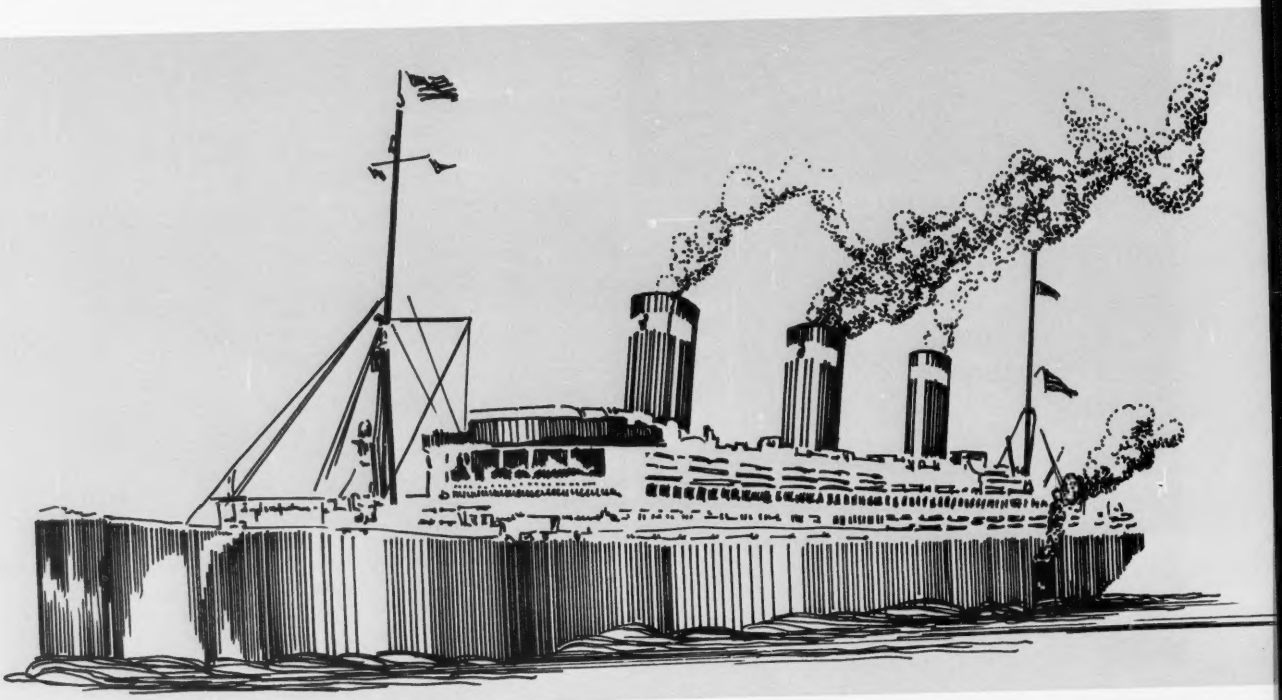
Modernization of the Ohio River navigation system permits a continued expansion of freight-carrying capacity, at a combined public and private investment per ton-mile of cargo carried far lower than that of any other surface mode of transportation. In its *1972 National Transportation Report,* the U.S. Department of Transportation projected an incremental private capital requirement of U.S. railroads to 1980, leaving out of account all public funds, of about $32.30 for each 1000 ton-miles of railroad freight projected for that year. By contrast, the corresponding figure for water carriage, after adding in all public as well as private investment, was only $6.84.

By locating in the Ohio Basin, a large sector of American industry derives more output per dollar of investment, thereby reducing the investment required for any given volume of production and releasing large sums for needed investment in facilities which add to social and environmental values. These include, for example, clean air, clean water, noise abatement, and occupational safety.

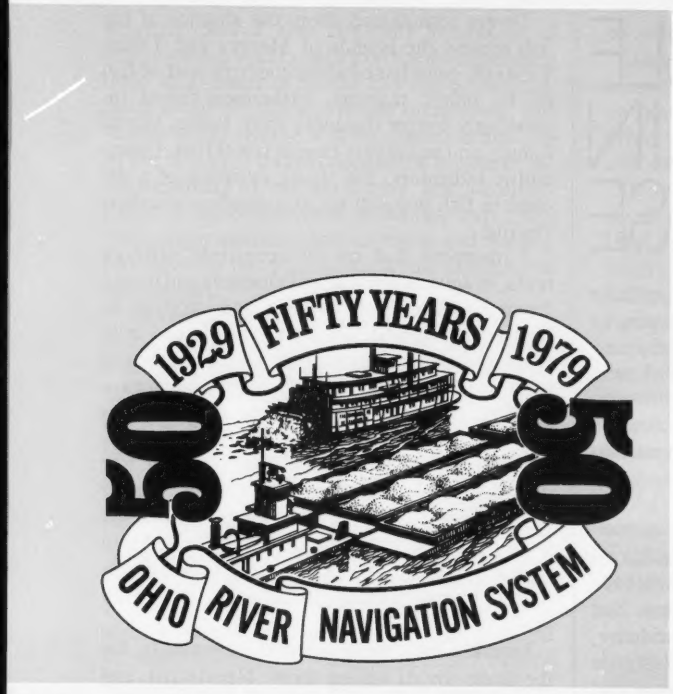
We have no way to estimate the dollar amounts of private investment which are conserved by the enhanced productivity of the $56.4 billion cited in the Ohio Valley since 1950, but there can be little doubt that it runs into hundreds of millions. The continued increment to the productivity of investment money in the future development of the Valley promises a significant availability of additional funds for the nation's program of environmental enhancement and of occupational health and safety with an associated reduction in interest rates.

The critical role of the Ohio River System in the U.S. energy program lies principally in its immense, low-cost, coal-carrying capability. About 65 percent of all U.S. coal production is mined in the Ohio Basin. In 1976, the Ohio and its tributaries carried over 15 percent of all the coal produced in the country, and this percentage is growing. In fact, from the five-year period 1967-71 to that of 1972-76, of the total increase in the nation's coal production, 21.5 percent consisted of the incremental coal tonnage carried on the main stream of the Ohio River.

The nation's energy program is now set on a course of greatly increased reliance on domestic coal. It is evident that the Ohio River will play a greater role in achieving this goal than any other single transportation route in the country. The nationwide production target of 1.2 billion tons by the mid-1980s will mean an increase of 535 million tons over 1976. The growth of the Ohio River share of the total is accelerating. We cited above the 21.5 percent share as between the two latest 5-year periods. In the latest year, however, from 1975 to 1976, the Ohio River's share in the national



The setting sun frames the pilot house of an Ohio River towboat.



tonnage increment was not 21.5 percent, but 34.7 percent.

The Ohio River system is likewise a vital distribution facility for the domestic oil refining industry, exercising substantial restraint on costs of gasoline, fuel oil, and other products throughout the region. Indeed, most of the gasoline and fuel oil consumed in such states as West Virginia, Kentucky, and Tennessee, is delivered from U.S. interior and Gulf Coast refineries by river barges. This movement contributes substantially to the efficiency, competitive strength, and growth of domestic refining, exercising restraint on the importation of high-cost refined products and thus alleviating the burden of petroleum imports on the nation's balance of payments.

The Ohio River locks and dams provide improved water supply for countless communities and industries resulting from the stable pools created by the dams. Such benefits are of critical importance to the great cities on the main stem—Pittsburgh, Huntington, Cincinnati and Louisville for example, and on the Kanawha and the Monongahela—where failure of any of the navigation dams would drastically impair domestic and industrial water supply.

Facilities for recreational boating enjoyed by millions are among the significant values of these projects.

This look at the history of the Ohio River navigation system, the economics and impacts on people, demonstrates ample reason for a celebration in the grand manner. During the fall of this year, citizens, industry, local and governmental leaders will participate in a partial re-enactment of that 1929 river tour. Towboats, vessels of the Coast Guard and the Corps of Engineers, and a specially outfitted barge containing historical displays will make stops at some cities along the Ohio.

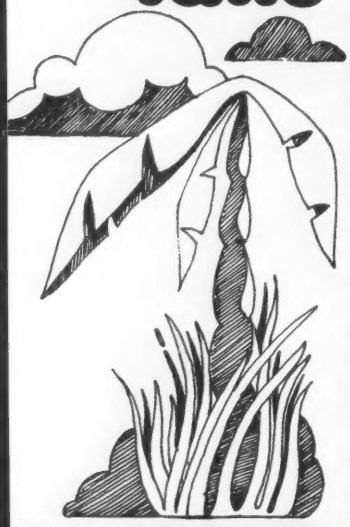
There will be speeches and presentations and the dedication of the Smithland Locks and Dam—all part of a celebration of the 50 years since the Ohio River Navigation system was completed. As I said at the beginning, they will again hail a "new" Ohio that has served well and promises to serve even more the next 50 and the next and so on.

It is my earliest hope that all who join in this celebration will derive new inspiration to do their part in bringing the Modernization Program to early consummation. In this way, they will serve their fellow Americans and their children and grandchildren as they were served by the dedicated men and women who conceived and sponsored the original system and bestowed upon this generation the blessings of an efficient inland navigation system in the industrial heart of America. ■

TROUBLE IN PARADISE

by **John C. Fine**

short take

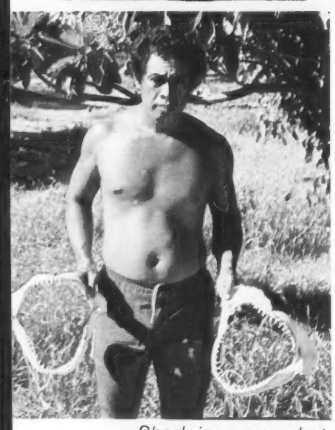


From the first settlement of the magnificent South Pacific islands and atolls, dumping of human refuse and waste directly into the surrounding water has been traditional. With relatively small native populations, the shallow lagoons could cope. They dispersed the waste and distributed it over a wide area—where it eventually merged and dissolved with the ocean water that continually flushed the lagoons through passes in the barrier reefs.

With the modern era's tremendous influx of tourism, however, huge hotel complexes have arrived beside the once tranquil lagoons. Not only did the residues from digging, dredging, construction and runoff from land clearance dump into the lagoon, but a daily sewage and waste effluent (detergent and kitchen waste, solvents, chemicals, insecticides, etc.) on a scale never before known in tropical Polynesia. Whether and to what extent the marine community can withstand such population pressure pollution is uncertain.

I had the opportunity to study the Moorea, French Polynesia, lagoon and the ocean environment outside the reef over a recent five month period. Coral in the lagoon was silted over. Water clarity varied from very poor to fair (3-25 feet visibility). Flocculent matter was often suspended in the water, untreated sewage floated about, brown scum slicks—apparently kitchen dumpings—were common. Detergent foam was present on a daily basis, oil and gasoline patches appeared periodically, and large coral areas were dead or dying where artificial "tuamotus" (jetty-like islands of dirt and sand built from shore out into the lagoon) had been built. Outside the reef there was evidence of depletion, breakage and coral damage, flocculent matter in suspension and moderate encroachment by *Acathaster planci*—the Crown of Thorns starfish.

In five months of diving I observed but one tiny lobster, an ominous sign in an area of coves, grottoes and other normal lobster sanctuary. Fishing, the principal occupation of the island's native population, was done with spear gun, net or from rapid bonita boats. Following flocks of feeding sea birds, the boats pursued the tuna with crude but efficient handmade lures, barbless hooks and long bamboo poles.



Shark jaws are a hot item in gift shops throughout Polynesia. The sharks are massacred for the sole purpose of obtaining the "trophies," with no thought given to the balance of nature. (Photos by the author.)

Mr. Fine is a New York State attorney at law.

Divers complained about the absence of big fish around the islands of Moorea and Tahiti. Tahitians complained about the high cost of fish in the public markets. Fishermen fished increasingly longer distances from home, stayed longer, and seemingly caught fewer fish. Unscientific indicators, but strong evidence of a decline in fish populations as a result of overharvesting.

I observed that on all accessible offshore reefs, in areas where the reef channels and passes formed rock ledges, caverns and grottoes as natural fish havens, the rocks were laced with scars made by spearguns, their pointed barbs and steel shafts glancing off the rocks' surfaces—clear evidence of fishing pressure. Native access to compressed air cylinder or SCUBA tanks was quite limited in the islands; their feats of free diving were legendary, however, as were their decimations of the reef communities. On the occasions I dived with the Tahitians using SCUBA, they spearfished, often massacring entire reef communities—with no view toward husbandry.

Inedible fish were speared, seemingly for the sheer joy of killing them. Needle fish and trumpet fish were regularly thrown up on the rocks and abandoned to rot in the sun. No attempt was made to conserve coral, which was ransacked for profit. Shells were collected indiscriminately, often by breaking up and destroying large coral beds. Fishing with dynamite also occurred in Polynesia, but was less prevalent than I discovered it to be in Micronesia.

In addition to the more traditional methods of fishing, a French military officer assigned in the out islands since 1964 described a chemical native fishermen used, derived from a local plant form. Released by free divers, the chemical had a narcotizing effect on fish—killing whole communities. Authorities have made some attempts to control the distribution of this substance and scientists at the Tahiti Botanical Garden apparently experimented with its use as a shark repellent. Although the French officer refused to discuss the composition or origin of the chemical for fear its usage would spread, it appears that every Tahitian fisherman knows about it and its use in the out islands is widespread.

It was impossible to adequately judge the effects of pollution on marine life in the lagoon areas without known recorded samples or standards taken years ago for comparison. Yet, all the indicators of pollution were present: lack of water clarity, flocculent matter in suspension, solid human waste present in quantity—the result of sewage being pumped directly into the lagoon through visible outfalls—algae and plankton growth, and dying coral colonies.

This trend could still be reversed. The great

diluting power and constant exchange of lagoon/ocean water could stop the damage being done in a matter of weeks and the marine colonies could quickly rejuvenate themselves. Reversal would require a comprehensive analysis of the effects of human population pressure, the establishment of tourism quotas, and the elimination of direct sources of pollution—especially from major sources such as hotels and resorts. Moratoriums on construction would also have to be imposed.

Governments are reticent about controlling tourism, particularly in areas where tourists provide the major source of revenue and jobs. Yet, the continued degradation of the natural beauty of these areas will eventually kill the goose that laid the golden egg. Clear and present danger is evident and visible to any trained observer.

The relatively unpopulated Tuamotu Islands provide a textbook case study. The largest Tuamotu atoll, Rangiroa, has a population of about 1000; one of them is former lobsterman Serge Arnoux, underwater pioneer and explorer and a resident of the Tuamotus for eight years. At its peak, his lobster business operated two or three boats of its own and also bought lobster from the Tahitians. The crustaceans were abundant on the reefs and Serge flourished—for about two years.

A few months ago I asked Serge why the business folded and why I had seen but one lobster in five months of diving. "There are no more lobsters. The Tahitians took everything; babies, females with eggs, everything. It was a good business, but they saw us doing well and began to cash in on it. The lobsters couldn't reproduce, so now there are no more lobsters unless you go way out to the small islands," Serge said sadly.

There are no more. That was the plain fact resulting from an indiscriminate harvest for profit.

Serge had me Anglicize a sign he was putting up in the hotel he manages in Rangiroa: "It takes 10 years for a 30 kilogram Napoleon fish to grow . . . it takes only a second to kill it with a speargun. Don't be trigger happy!" The sign was prompted by what Arnoux sees as the imminent fate for marine life in the islands: extinction. Although the Tuamotus abound with fish, the establishment of a fishing cooperative with a modern refrigeration system on Rangiroa, the only one on the out islands, makes fishing's future questionable. Refrigeration encourages the accumulation of large catches. Wholesale commercialization has begun, since Japanese refrigerated ships can now dock at Rangiroa and take on fish direct for export. A far cry from the limited catches that could be sold outside the islands' needs, dictated by the small, old ships that would ice the fish in their holds and be able to sail only as far as the ice would last.

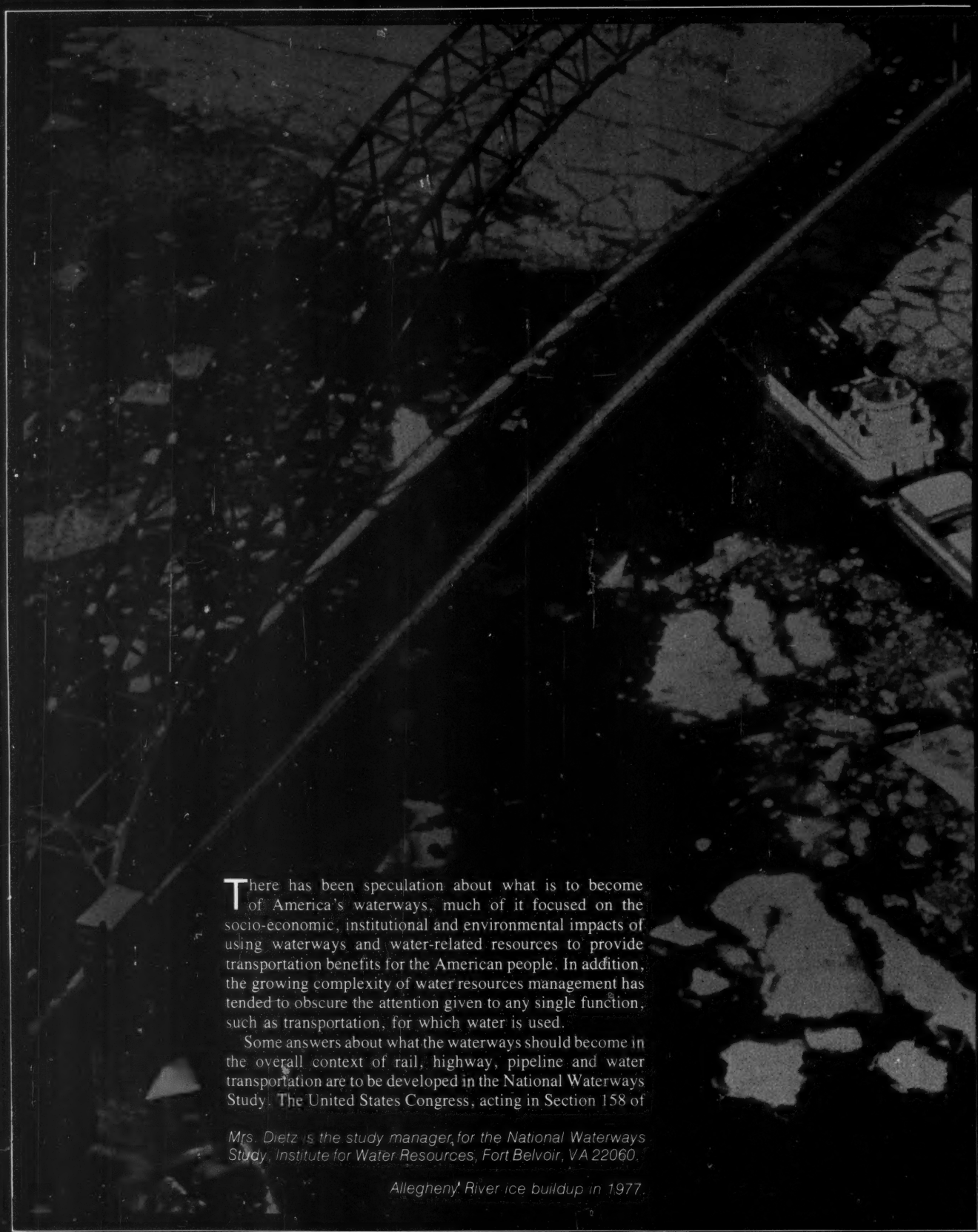
There is a quick profit to be made, if only a temporary one. Given that premise, there can be no doubt about man's willingness to grab it. What happened to the lobster can, and likely will, happen to the fish.

From time immemorial, coral has been a precious commodity, highly valued in jewelry. Hard coral in its various color phases has been sought after as a prize worthy of great risk. Divers hazard great depths in search of corals, enduring extreme hardship and often suffering crippling diving accidents or death. In the South Pacific, hard pink and rose coral grows abundantly. On remote islands such as Rangiroa, where sharks and swift current made it difficult to harvest and geography made it difficult to market, large gardens of coral flourished. Recent haphazard harvests, correlated with increased air service and tourism, have caused a great deal of breakage and depletion. If not controlled, total depletion of the out island coral will eventually occur as it has already on the more populous islands.

Periodically and unexplainedly, the Crown of Thorns starfish makes an appearance in an area and causes damage to coral by grazing over living polyps—leaving behind dead calcium carbonate skeletons. *Acathanster,* beautiful to observe underwater, was making inroads on Polynesian reefs and lagoons in the large areas I surveyed, and causing relatively significant damage to coral colonies and non-colonial madrepores. Although my experiments toward a relationship between the removal of the Triton sea snails by collectors and the increase of the Crown of Thorns were inconclusive, the Triton is now so scarce in this environment that its role in controlling the starfish must be discounted. In time, if it continues to be unchecked, the Crown of Thorns will present an increasing threat to the balance of nature in these islands.

The plight of the South Pacific is classical; it presents a case for environmental damage by greed, over harvest, arbitrariness and just plain pressure from too many people. The marine ecology is everything to the existence of these islands. Once destroyed or despoiled, the islands will lose their basic appeal and attraction and the natives will be bereft of the natural resource that today provides their subsistence.

Scum floats on the surface—a result of grease and sewage being discharged directly into the lagoons.



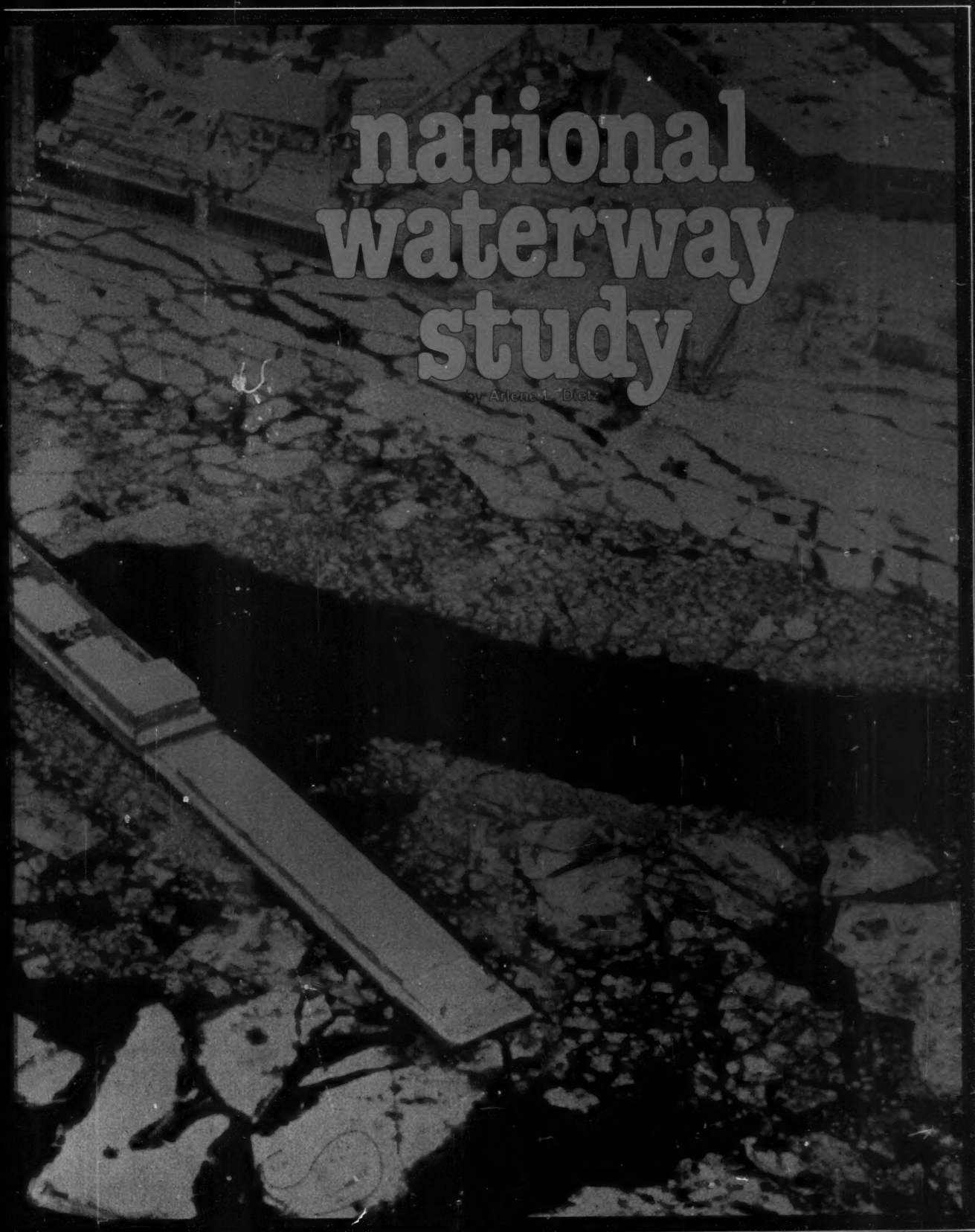
There has been speculation about what is to become of America's waterways, much of it focused on the socio-economic, institutional and environmental impacts of using waterways and water-related resources to provide transportation benefits for the American people. In addition, the growing complexity of water resources management has tended to obscure the attention given to any single function, such as transportation, for which water is used.

Some answers about what the waterways should become in the overall context of rail, highway, pipeline and water transportation are to be developed in the National Waterways Study. The United States Congress, acting in Section 158 of

Mrs. Dietz is the study manager for the National Waterways Study, Institute for Water Resources, Fort Belvoir, VA 22060.

Allegheny River ice buildup in 1977.

national waterway study



The impact of 1973 flooding at Locks and Dam No. 26, Alton, Illinois.

the Water Resources Development Act of 1976, directed the U.S. Army Corps of Engineers to undertake a navigation-oriented study. The overall NWS objective is to identify and analyze alternative strategies for providing a navigation system to serve the nation's current and projected transportation needs. To meet this objective the study will:

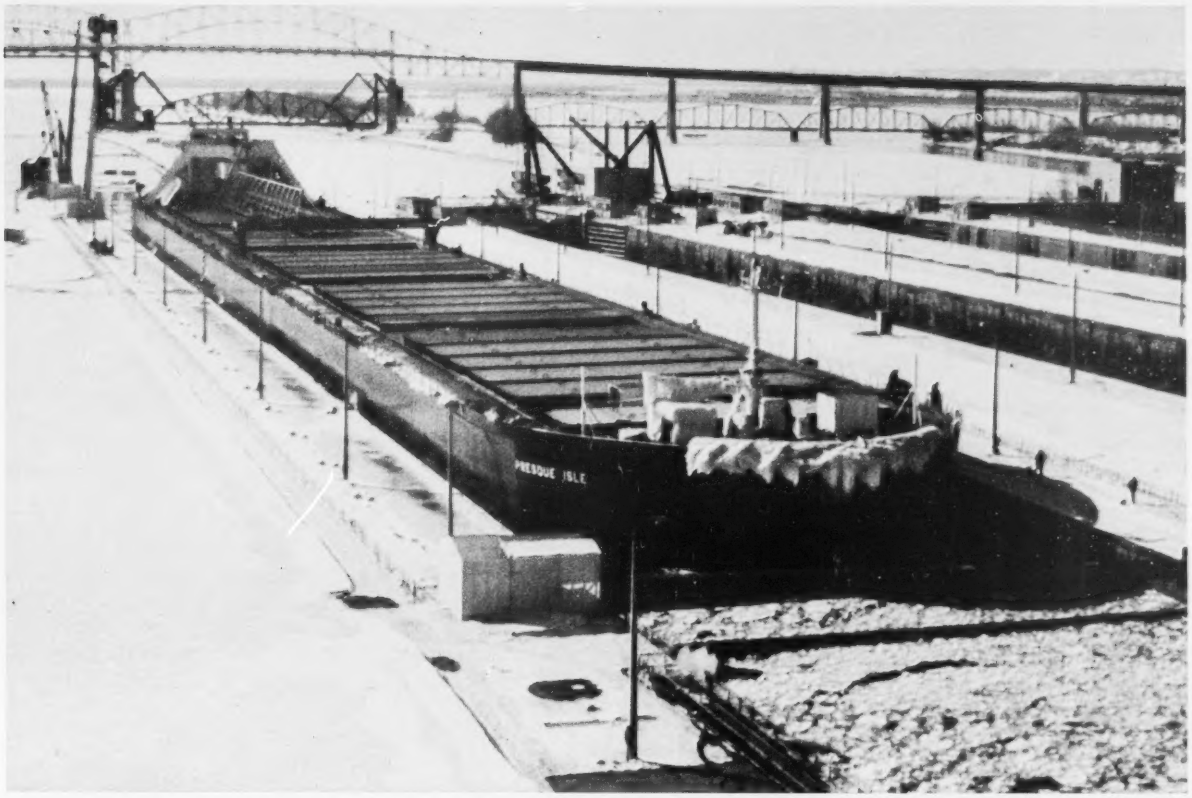
- Project the nation's potential requirement for water transportation. The study will forecast the demand for waterways transportation considering both complementary and competing modes. (Demands for commercial transportation, as well as defense and emergency needs, will be considered under alternative future scenarios.)
- Assess the capability of the existing waterways system to meet both current and projected national needs. The study will examine the capability of the current navigation system to handle present and future traffic. System level constraints will be identified.
- Examine the relationship between the use of waterways for transportation and for other purposes. Conflicts between navigation and other uses of the waterways (e.g., hydropower, recreation, irrigation) will be identified where they may occur.
- Develop and evaluate alternative strategies to meet the projected national transportation needs. The strategies may involve operational, structural, managerial, institutional and/or regulatory changes.

Based on the study results, the Secretary of the Army will recommend to Congress one or more alternative courses of action.

Study management has been assigned to the Institute for Water Resources, and Corps offices throughout the nation are active contributors. Other study participants include the Department of Transportation, Maritime Administration of the Department of Commerce, the Council on Environmental Quality and the National Transportation Policy Study Commission. Most of the technical studies are being conducted by contractors from the private sector. State agencies, other organizations and the public are also being asked to provide input.

Background

The existing system of waterways, ports and harbors developed in the United States is the result of a long range endeavor that can be traced to the beginning of the nation. One of the earliest and most persistent themes of American history relates to the use and improvement of natural waterways. The first North American explorers saw the value of linking the natural streams and lakes into a system that would promote exploration and economic and social development. The National Waterways Study seeks new dimensions in which the waterways and ports may better serve transport needs of the United States.



Locking through the ice at Presque Isle, Michigan.

The historical development of the waterways system has proceeded, for the most part, on a project-by-project rather than systematic basis. Each generation has interpreted the value of the waterways in light of its special needs. In recognition of the changing social, economic, institutional and environmental criteria, it has become clearly evident that the system needs reevaluation. It is known that some features of the system are not compatible with today's multiple-purpose water uses or needs. This is the major reason for Congress' directive to the Corps of Engineers to review the nation's waterways system and assess its capability to meet the future needs. This study is the first opportunity to develop a comprehensive framework for future decision making for the waterways.

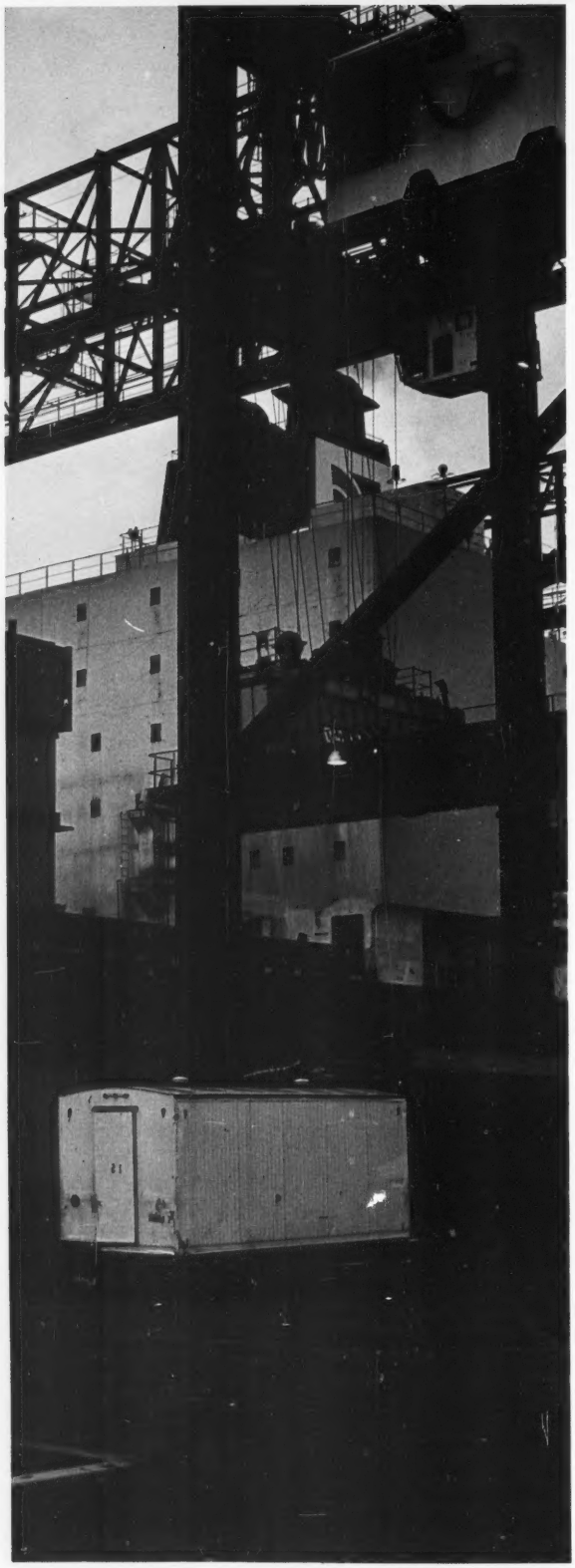
The Study Design

The first task of the National Waterways Study has been to develop an inventory of the existing system and the commodities which move on the waterways, and prepare a description of that system. The development of future scenarios precedes the second group of major activities which include projecting commodity flows and assessing the capability of the existing system to meet these flows. This is followed by assessment under the future conditions. Development and evaluation of alternative strategies follow the identification of constrained segments of the nation's system.

The study must, in its evaluation and development of alternative strategies to meet the commercial navigation needs, relate the transportation function to the many other essential functions served by the water resources of the nation, including municipal and industrial water supply, hydroelectric power generation, recreation, waste disposal and conveyance. Flood control, drainage, shoreline protection, and fish and wildlife habitat protection and enhancement are also essential elements in the multiple-purpose planning context.

In appraising the commercial transportation potential of the nation's waterways, it is important at the outset to understand that programs which facilitate other uses for the water resource may either strengthen the navigation capability, as when flood control reservoirs provide storage to regulate stream flow, or diminish the capacity, as when withdrawals of water for irrigation place seasonal limitations on the availability of streamflow. Thus, the forces of competition for the water resource, together with the related management plans, strongly influence the role of water transportation in relation to the other modes of transportation covered in national transportation planning.

Although continuing pressures for national and regional growth spur on moves to expand transportation capabilities, it seems apparent that the mission of institutions involved in water transportation is focusing more on improved opera-



A Sealand container at the Port of New York.

tions and maintenance, modernization of existing waterways and replacement of outmoded facilities—not on major system development and expansion. There are also questions about the safety of navigation facilities and the reliability of the system in sustained use. Many improvements were installed decades ago, and breakdowns at sensitive points are a concern.

Further, competition for the use of water resources is intensifying, especially in areas without an abundant supply. Cultural, socio-economic and environmental concerns have also come to the forefront of public consciousness and the relationship between any changes in the water transportation system and these concerns requires in-depth examination.

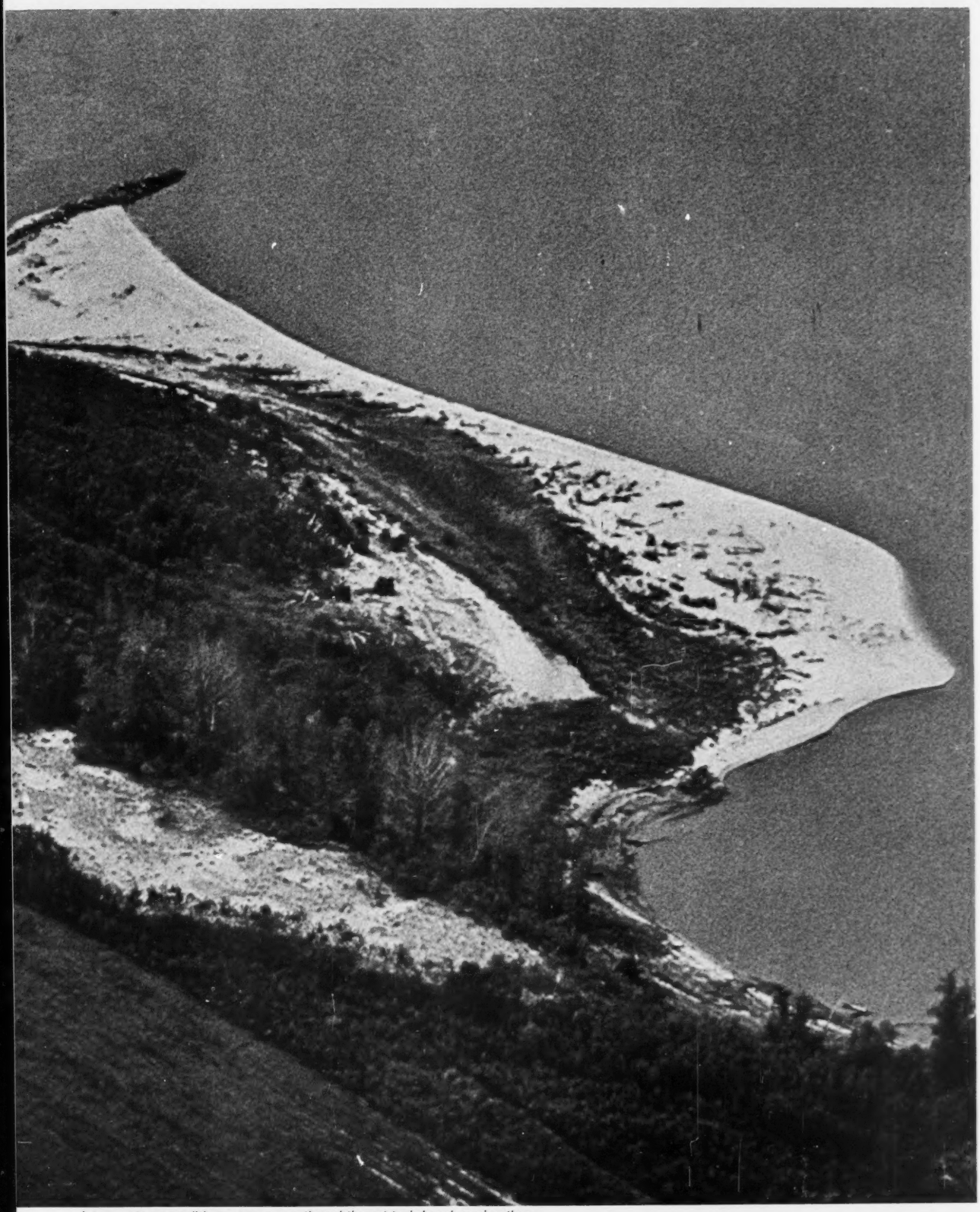
Inland waterways provide low-cost and energy-efficient transportation for bulk commodities and shippers of large quantities of these goods usually prefer water transportation, although railways offer direct competition for these services. The advantages of rail transport are speed and a geographic range that extends beyond the confines of waterway locations. Pipelines, of course, offer the greatest advantages of speed, efficiency and cost for moving a high volume of suitable commodities. The potential relationship between pipeline development and the patterns of water transportation is a topic of current importance for the U.S. economy. Highway and railway firms generally compete for the movement of finished goods in small lot, high-volume shipments over relatively short distances.

Technological improvements are influencing the transportation industry, generally by lowering terminal operating expenses and thus reducing transportation costs. Although the distribution of technological advances varies throughout the industry, there are three general categories of improvements: (1) transportation planners and managers are gaining the benefit of automatic data processing, distribution and control equipment; (2) containerization and its associated terminals and equipment are finding widespread use; and (3) carriers, including rail, highway and waterway equipment, are being improved. The location of the service sector may also influence future transportation needs.

Foreign trade also has an influence on technology and transportation patterns. New ship designs such as LASH and Seabee have brought an unprecedented degree of foreign shipping into America's inland waterways. There has also been planning for development of deepwater ports for unloading large bulk carriers and there is an anticipated need for offshore oil terminals.

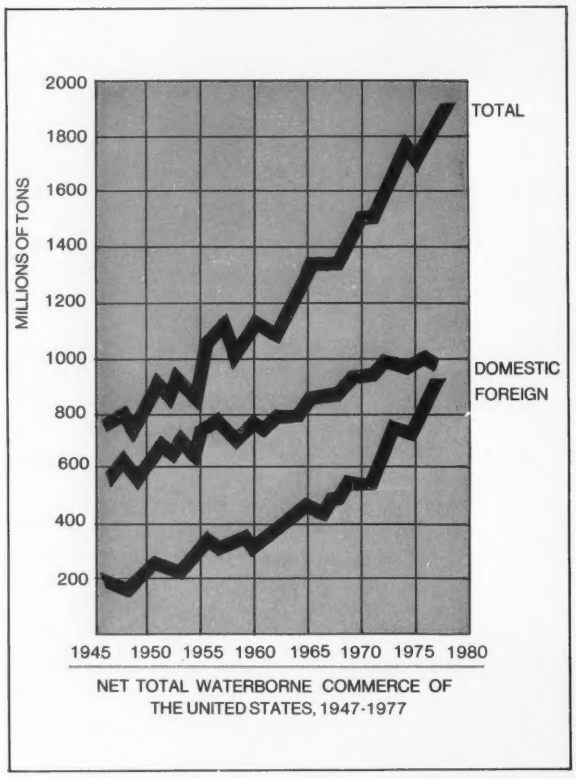
Energy shortages in the coming years will increase the importance of energy efficiency in all types of transportation as the impact of an energy-constained economy is felt across the nation. The prospect of energy shortages reinforces the realization that the development of transportation networks will no longer be a major force in the geography of economic and social growth. It is likely that transportation planning will be increasingly guided by national economic needs and policies to allocate scarce resources, promote conservation and sustain environmental preservation efforts.

The growing complexity of both water resource planning and general transportation planning has tended to obscure both the role of the waterways in transportation and the value of the waterways and ports to the nation.



Low water conditions are a continual threat to inland navigation.

Today there is a wider public knowledge of the interstate highway motor carriers and the railroad freight train as movers of commodities than there is of the waterways, tows, ships, and related facilities. The highways and railroads are, of course, vital elements in our national transport system. The waterways and ports still seem to be faced with the requirements for increasing total transport capacity to meet both foreign and domestic commodity transportation needs. It is important for the public to have a good understanding of each element in the transportation system so that a truly integrated system may be gradually developed—serving the nationwide need for freight movement in the most effective, economical and energy-efficient manner.



NET TOTAL WATERBORNE COMMERCE OF THE UNITED STATES, 1947-1977

The Waterway System Today

Currently, nearly 26,000 miles of commercially navigable waterways are in use, in addition to the shipping lanes of the Great Lakes and the coastal trade routes. Ninety-five percent of the United States population lives in states served by this system. These waterways are served by more than 155 commercial harbors and ports operated by private industry or by local or state governments.

Navigation improvements along the waterways include locks at 265 sites, channel alignments, bank stabilization, cut-offs, dredging, and clearing and snagging operations. The Corps of Engineers operates most of the locks, maintains most of the improved waterways and is also responsible for a portion of the dredge fleet capacity required for maintaining the channels and ports.

Since 1824 the Federal government has invested about $10 billion in the development and maintenance of the inland and intracoastal waterways and in the Great Lakes and coastal harbors. Present annual maintenance costs for these facilities range from $350 to $400 million.

Approximately 1.9 billion tons of freight move along the waterways and through the ports each year. The foreign trade component is nearly equal to the domestic flow and is growing at an accelerating rate. As shown in Figure 1, both foreign and domestic commerce approached 1 billion tons in 1977. The waterway system provides effective transportation for movement of crude and refined petroleum, coal, grains and fertilizers, industrial chemicals, iron ore, iron and steel products as well as other bulk commodities.[1] Energy commodities, petroleum and its products and coal, dominate foreign and domestic waterborne trade and accounted for 61 percent of all waterborne commerce in 1977. Most of the movement is of foreign origin. The next largest domestic commodity group moving by water—grains—is predominately for export.

In the three decades between 1947 to 1977, the volume of waterborne commerce increased from 700 million tons to 1.9 billion tons. Domestic commerce has shown consistent growth, beginning with the movement of 579 million tons in 1947 and leveling off within a range of 970 to 990 million tons between 1973 and 1977. Foreign commerce has grown at a much more rapid pace, from 188 million tons in 1947 to 935 million tons in 1977. Foreign trade represented about 25 percent of total waterborne commerce in 1947, but it currently accounts for about 50 percent of the total.

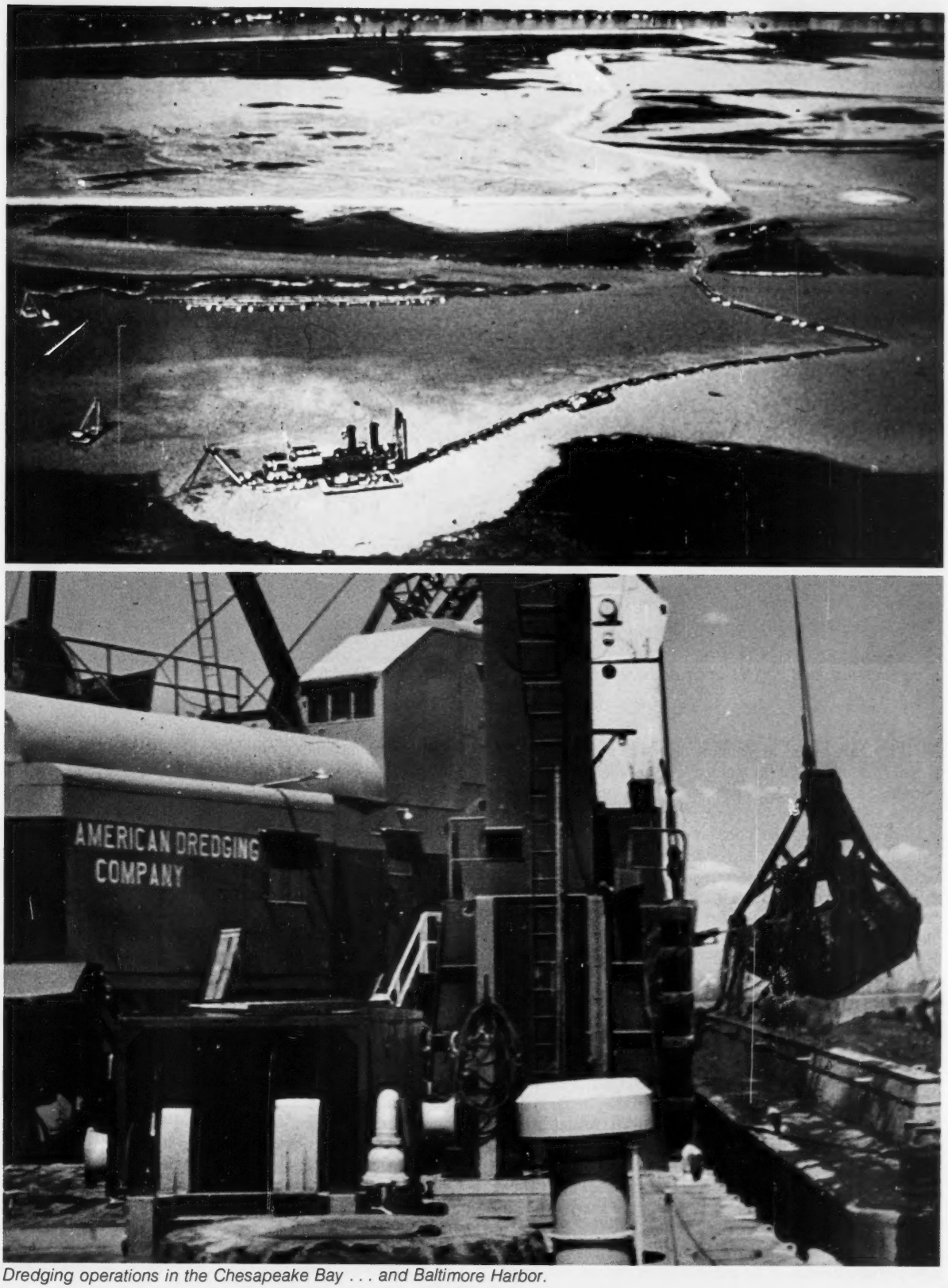
Future Scenarios, Study Elements and System Capability

In spite of the lack of explicit transportation planning guidelines, there is a growing recognition of the need for efforts toward development of an integrated, multimodal transportation system including a comprehensive plan to guide waterway development as part of such a system. The purpose of a such a plan is to further national goals and objectives through a balanced approach in which technical, economic, social, institutional, and environmental considerations are carefully considered in relation to both the transportation and other resource needs served by each segment of the waterway system.

Three elements of the waterway system need strong emphasis in any discussion of water transportation planning. These are: (1) basic freight movement capability, (2) safety and reliability, and (3) potential defense and emergency roles. Knowledge of these aspects is necessary to define the functional role of water transportation and understand the potential for integration into a multimodal, national freight transportation network.

Assessment of the transport capability of a waterway sys-

[1]The National Waterways Study has produced a set of 19 maps depicting the basic physical characteristics of the system on one national and four regional maps, and showing all major commodity flows for the nation on separate national maps. These maps are available through the National Waterways Study, U.S. Army Corps of Engineers Institute for Water Resources, Ft. Belvoir, VA 22060.



Dredging operations in the Chesapeake Bay . . . and Baltimore Harbor.

A deteriorated lock wall at Lock and Dam No. 3 on the Monongahela River (CofE photos)

tem is a highly technical planning task. The system required to meet future needs, as guided by the alternative future scenarios, as well as the capability to meet current demand, must be appraised. The full range of other water uses, current and projected, must be considered in any assessment of waterways capability, as must a wide range of transportation needs including defense, security and emergency. Both supply and demand perspectives must be maintained throughout the capability analysis, and there may be need for qualitative studies of the relevant waterway instituitions.

These inventories and investigations—the technical study elements—should lead to the identification of significant constraints throughout the waterway system. Thus, problems and issues will be brought into focus and a realistic estimate of waterways' capability, present and potential, made possible.

Questions concerning the safety of navigation facilities, their operational procedures, and the reliability of the system under sustained use are, of course, closely related to the capability question. But these latter questions have special significance for the U.S. waterways where many of the navigation improvements were installed decades ago. There is consequent concern in many cases for the sheer structural adequacy of these improvements.

Questions of dam safety for example, as well as the general safety of all elements of the transportation system: rail, truck, water, pipeline and air, are today sharply etched on the public mind. Less dramatic, but not unprecedented events, such as the collapse of lock walls, could also cause loss of life. However, breakdown of waterway service due to functional failure of a critically located major structure such as Locks and Dam No. 26 on the Mississippi River or Gallipolis Locks and Dam on the Ohio River would have more serious national implications. Hazards resulting from moving dangerous cargoes on the water are of concern to the public, however, water transport has several advantages over other modes in the movement of hazardous material. Other navigation hazards stem from the geometry of specific waterways, often leading to the need for safety related dredging.

Plans for the waterways will be significantly shaped by these safety factors, some of which are closely related to the age and operating characteristics of essential system facilities now under heavy use.

The nation's dependence on a reliable and efficient freight transport system and the underlying planning and management which makes it possible, gives transportation planning a crucial part in national economic defense and emergency planning. The history of waterway use testifies to the important part the waterways have played in national defense during every major war. The intrinsic value of the waterway as a logistical element in defense planning is widely recognized. However, the low redundancy of much of the inland

A modern containerized port on the West Coast.

waterways system makes it vulnerable—with consequent implications for national defense, security and emergency functions.

Study Findings

The National Waterways Study goal is to develop a comprehensive framework for future decision making about the use of the U.S. waterways for transportation purposes. Conducted within a multiple water resource use context and the context of the total transportation system, the study can achieve this goal. As a planning study, not a research and development effort, no new state-of-the-art analytical tools or models will be forthcoming. The study results will be based on ten national scenarios. Strategies set against these scenarios will be designed to achieve a framework for realizing an effective water transportation system through the year 2000. For NWS planning purposes, the nation was subdivided into approximately 20 reporting subdivisions. These cover the entire continental United States plus Alaska, Hawaii and the Caribbean. It is for these subdivisions that strategies will be proposed.

The findings are a consequence of evaluating the capability of the present system to meet needs, as developed from the alternative scenarios, on only those segments where future constraints are foreseen. These constraints will have been identified in the study by the end of this year. The projected demands for each scenario are set against the capability of approximately 60 analysis segments. Options to overcome limitations of capability cover a broad range of modifications including state-of-the-art engineering and institutional options. Identification of the impacts will be made for each scenario for each of the strategies. Spring 1980 is scheduled for completion of strategies evaluation.

Many conditions cannot be accounted for in scenarios. For example, some types of institutional and conflicting use conditions do not lend themselves to detailed quantification of cause and effect, such as that required for adjusting commodity flows. These may, therefore, require reassessment of not only commodity flows but capability and alternative strategies for the segments.

The study conclusions will be developed regarding the nature and extent of potential modifications (physical, operational, and/or institutional) to the system and the scope and timing of implementation studies, research and development efforts, as well as policy and institutional studies. The study's end product will be a planning framework to prioritize and conduct future water transportation planning. Congress will then have a structure with sufficient options to formulate its future decision making in water transportation.

Regional Ground Water Systems Analysis

by **G. D. Bennett**

During the coming decade, pumpage of ground water to supplement surface supplies is expected to increase dramatically throughout the country. The rapid growth of cities, particularly in the water-short southwest, will be a prime contributing factor; the desire to develop water supplies capable of weathering extended drought will be another.

Large supplies of water will be required for new energy-producing industries, particularly such activities as power generation and the operation of coal slurry pipelines. Irrigation is fast becoming a routine component of agriculture even in areas traditionally regarded as humid and well suited to dry farming; the development of center-pivot equipment, in which a moving sprinkler pipe rotates about a central well and irrigates a circular area, has caused a rapid increase both in irrigated acreage and in emphasis on ground water as a source of irrigation supply. Also, environmental objections to large surface reservoirs are forcing planners to consider ground water as an alternative source of supply for all applications.

This increasing use of ground water is certain to have both varied and widespread impacts. From a strictly hydraulic point of view, all pumpage must result in a lowering of ground water levels, and this in turn will affect all users of ground water in the area of influence. In addition, pumpage tends to reduce the available surface water supply by reducing natural discharge of ground water to streams, and in some cases by inducing direct seepage from streams to the ground water system.

In some instances the pumped ground water is returned to the stream system or, through artificial recharge, irrigation field seepage, or certain forms of waste disposal, directly to the ground water regime after a cycle of use. In these instances, the most critical impact may be one of degradation in water quality rather than of diminished supply. Pumpage may also have an impact on the structure of the rocks in the area. Sustained withdrawals from some types of aquifer can cause compaction of the acquifer and overlying formations, which results in subsidence of the land surface.

Mr. Bennett is a hydrologist with the U.S. Geological Survey in Reston, VA 22092.

In the development of ground water, as in the development of any resource, well advised management can make a great difference. The consequence of pumpage will depend to a large extent on the way in which the pumpage is implemented. If the results of various courses of development are understood in advance, planners will be in a position to choose the course for which the ratio of benefit to real cost is most favorable.

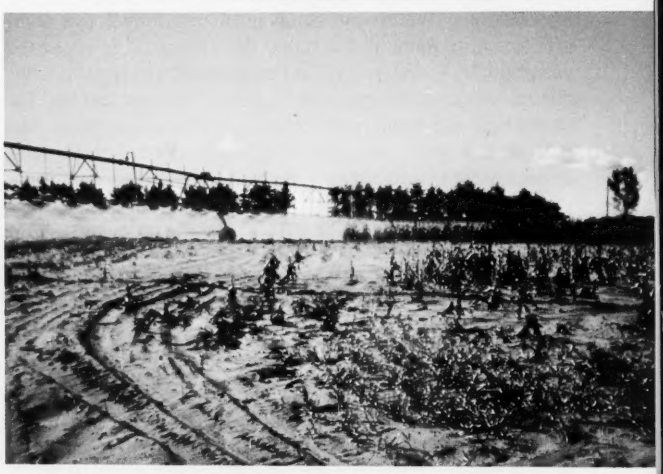
Even where no planning authority exists to guide and influence the development of ground water, an understanding of the consequences of various patterns of withdrawal is certainly necessary if society is to be prepared to meet those consequences.

Clearly the prerequisite to successful management is adequate information—particularly on the hydrologic impacts of various development alternatives. The requirement is for a predictive capability, through which the planner can estimate in advance what will happen if this or that scheme of withdrawal is implemented.

For a number of years, ground water investigations both within and outside the USGS have focused on the development and application of such predictive capabilities. In general, these efforts have been at a local scale, both because of limitations in the state of the science, and because the interest of planners has been largely at the local level. The anticipated increases in withdrawal over the next decade, however, will produce impacts which are regional in scope.

Ground Water and the Economy

The significance of ground water to economics can be illustrated through two examples. In California's Central Valley, pumpage for irrigation had been curtailed prior to 1977 and replaced with surface water in an effort to stem the land subsidence that had accompanied earlier heavy withdrawals. In 1977 drought caused a failure of surface water supplies and there was widespread concern that the agricultural production of the Valley, a vital factor in the state's economy, would fall seriously short. As surface water supplies declined, however, pumpage from active irrigation wells was increased, idle wells were reactivated, and thousands of new wells were



Ground level view of center pivot irrigation in operation.

Skylab photo of center pivot irrigation systems in Nebraska.

drilled. Irrigation supplies were thus maintained throughout the growing season, and the impact of the drought on food production in the Valley was greatly reduced. With the passing of the drought, surface water has again become the major source of irrigation in the Valley.

This experience, however, illustrates the importance of ground water as a drought-resisting component in the total water supply, and shows the value of integrated management of ground water and surface water to meet current demands.

Another example of ground water's economic significance can be found in the northern Great Plains States, where surface water and shallow ground water sources are already committed to irrigation, and new sources are needed to supply the competing demands of energy production. The Madison Aquifer, an extensive but deep-lying and therefore little utilized formation, has been proposed as a potential source of water for mining operations, coal slurry pipelines and power generation. The feasibility of using the Madison in this way is currently the subject of intensive investigation.

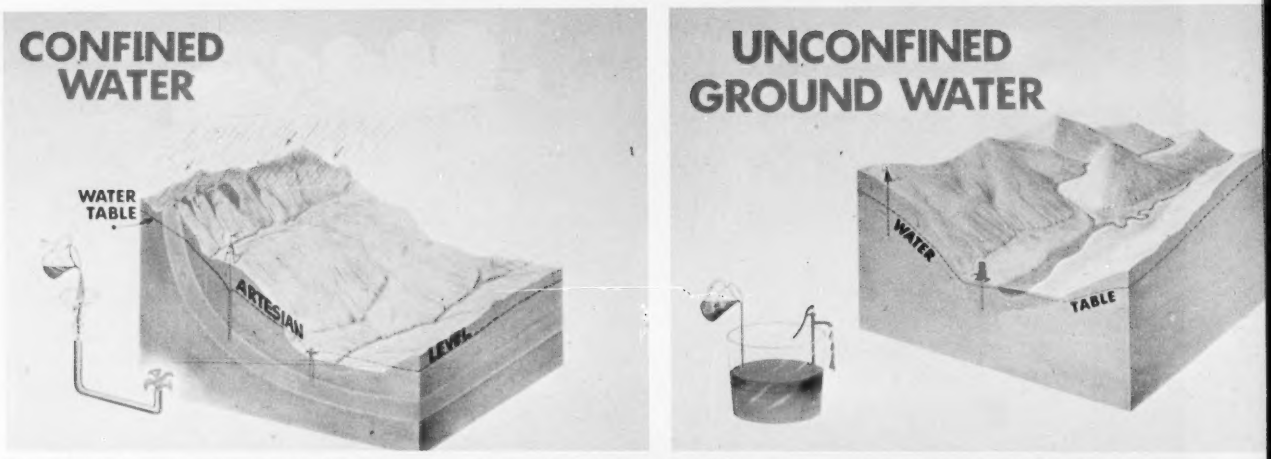
Whatever the results of these investigations, the competition between energy-related uses and other water demands will probably be a factor in the regional economy for many years to come. This situation will be repeated in other parts of the country as the effort toward greater domestic energy production intensifies, and in many instances ground water development will be proposed as the solution.

As these examples illustrate, the management questions facing the planner are basically economic issues. Some are clear cut; for example, any new draft on the ground water system must influence the pumping lift, flow rate, or quality of the supply to existing installations, and each of these factors has an influence on cost. The economic implications of other management questions may be less clearly defined, but they are real. Certain environmental impacts of pumpage, for example, may not usually be thought of in terms of dollars. However, if a development scheme is abandoned because of environmental considerations, a decision has implicitly been made to place a higher value on maintenance of the environment than on the benefit of the pumpage to the economy. This decision, intentionally or not, attaches at least a minimum dollar value to the environmental issue.

The need for management, in any case, is an economic need. Haphazard development of ground water will cost the nation much more than well-managed development. Successful management of any resource depends upon information, and, as noted above, ground water is no exception. An understanding of the natural flow system and of the way in which it will respond—hydraulically, chemically, and structurally—to imposed stresses, is a necessary prerequisite to ground water development planning.

The Nature of Ground Water Flow

The ground water regime is a dynamic system in which water is continuously in motion from areas of recharge to areas of discharge. In a typical ground water flow system this movement occurs through an extensive, heterogenous, but interconnected geologic framework. This framework generally includes permeable units, normally thought of as water-bearing zones or aquifers; and less permeable units, which were formerly considered confining zones (aquicludes) but are now more commonly thought of as semi-confining zones (aquitards).



The principal modes of ground water occurrence. In practice, the two conditions are never fully realized. Confined ground water always "leaks" through the confining beds; unconfined ground water is never truly unconfined except right at the water table. (Courtesy of S.W. Lohman, USGS).

The chemical quality of ground water is recognized to be a function of the processes, particularly interaction with the geologic framework, which have occurred along the path of flow. Thus chemical quality normally varies from one point to another in the flow pattern.

Prior to development in a given region, the flow regime is presumably in hydrologic equilibrium, with total recharge to the system equal to total discharge from it.

Pumpage disrupts this equilibrium, causing a withdrawal of water from storage and concurrent decline of water levels. As water levels fall, natural discharge from the system is reduced and recharge may be increased. In time these changes in natural inflow and outflow may be sufficient to balance the withdrawal; if this occurs, a new equilibrium is achieved in which recharge is balanced by the sum of natural outflow and pumpage, and depletion of storage no longer occurs.

Such an equilibrium, however, may not always be possible at a given rate of withdrawal. If the pumpage from a given system exceeds the reductions in natural outflow and the

It is important to recognize that the reduction in natural outflow just described implies that withdrawal of ground water must ultimately have impact on surface water resources. If, for example, a ground water flow system originally discharges to a stream, development of ground water will ultimately bring about a reduction in stream flow equal to the pumpage, if a new equilibrium is achieved and no increase in recharge occurs.

In some applications, of course, much of the pumpage is returned to the stream system after use; the impact on the stream is then largely one of degradation in quality, rather than of reduction in flow. The point is that ground water and surface water are both parts of an integrated hydrologic regime, and that a stress in either may have repercussions throughout the hydrologic system.

The total volume of water in storage as ground water is extremely high relative to the rate of flow through the system. This high ratio of storage to flow rate tends to encourage development of ground water from storage; it also means that the ground water system is a far more drought-resistant supply than most surface sources, and that conjunctive management of ground water and surface water is an effective method of weathering fluctuations in surface supplies.

Regional Aquifer-System Analysis

To provide management information on a regional scale, the Geological Survey has initiated a new series of hydrologic investigations—The Regional Aquifer-System Analysis (RASA) Program. This program represents a systematic effort to study a number of regional ground water systems, which together cover much of the area of the country and represent a significant element of the national water supply. Twenty-nine systems have been identified for study under the program; in general, their boundaries transcend the political subdivisions to which hydrologic investigations have often been limited in the past. The overall objective of the program is to assemble hydrologic information and create predictive capabilities necessary for effective management of the nation's ground water.

A regional aquifer system, as the term is used here, may be of two general types: it may comprise an extensive set of aquifers and aquitards which are hydraulically connected, or it may represent a set of essentially independent aquifers which share so many common characteristics that they can be studied efficiently in a single exercise.

For interconnected systems, the study objective will be to define the regional hydrology and to establish a framework—geologic, hydraulic, and geochemical—for detailed local investigations. Thus, the regional studies are expected to provide boundary flows for local studies, and to provide an overall geologic and geochemical background from which local investigations can be pursued.

For systems made up of independent aquifer units, the study objective will be to establish common principles governing the occurrence, movement and quality of ground water in the individual units. These principles should again provide the foundation for more detailed local investigations.

While each investigation will be designed to fit the particular problems of the study area, every project will utilize computer models, or simulations, to analyze the existing

hydrologic regime and to provide predictive capabilities by which the effects of future development can be estimated. The simulations will incorporate hydraulic effects, and, where necessary, such associated effects as land subsidence or solute transport.

Briefly, simulation refers to the process by which the characteristics of the flow system are represented by a set of equations which can be solved on a digital computer. The set of equations, the computer routines required for solution, and the input data (specifying the properties of the geologic framework and of the ground water, and outlining the problem to be solved) collectively constitute the "model" of the flow system.

Initially, simulation was regarded primarily as an aid in predicting the effects of future pumpage. In recent years, however, there has been a growing realization of the contribution the method can offer to the process of hydrogeologic investigation itself. Through techniques which range from simple trial and error calculation to sophisticated statistical analysis, simulation allows the investigator to test his hypotheses, to check the sensitivity of his results to various assumed conditions, and to generate a reasonable reconstruction of the existing flow system on the basis of available field data. By removing pumpage from the simulation, the hydrologist can view the flow system as it existed prior to man's intervention; this can be of invaluable assistance in explaining the observed water chemistry, and in estimating the extent to which pumpage has changed the natural hydrologic regime. Thus, in a number of ways simulation has made the analysis of regional hydrology a much more realistic goal than it was a few years ago.

Apart from its value as an investigative tool, simulation remains the most effective means of predicting the effects of future pumpage; the development of a workable model provides the water manager with the predictive capability required for successful planning.

In the Regional Aquifer-System Analysis Program, simulation will serve both investigative and predictive needs. For systems of interconnected aquifers and aquitards, a model of the full system will be developed, supported by more detailed simulations of local or subregional problem areas. For systems of independent aquifer units, the approach will involve simulation of representative units, with generalization of results to other units throughout the group. The simulations will be based upon a full assemblage of existing data, and upon such new data as required to fill critical gaps in the available information. In some cases collection of this new data will require extensive field operations.

Information will be assembled on the quality of water throughout each aquifer system, again by bringing together all existing information and collecting such field data as required to fill the gaps. An effort will be made to interpret this water-quality information in terms of the original flow pattern and the changes that have occurred in response to development, as inferred from the simulations. Using the water-quality data in conjunction with predicted flow patterns as derived from the models, some insight may be gained into future quality problems.

Products from each study will consist of a series of reports, beginning with summaries of data as it is assembled, and culminating in interpretive reports including the results of predictive simulations.

The program is expected to cover approximately 10 years, and to utilize such advances in investigative technology as may occur over that period. The average length of study will be approximately four years. Three studies were initiated in FY 1978, including the High Plains, the Northern Great Plains, and the Central Valley of California. Studies of the Southeastern Carbonate aquifers, the Northern Midwest Sandstone aquifers, and the Southwest Alluvial basins were initiated in FY 1979. Studies of the Atlantic Coastal Plain, the Southeast Coastal Plain, the Snake River Plain and the Central Midwest Carbonates will be initiated in FY 1980. The scope of each of these studies is outlined briefly below.

The study of the Central Valley of California is concerned with evaluating the effects of continued or expanded use of ground water as an adjunct to surface water in the irrigation system, with particular reference to land subsidence problems, and to the use of ground water during periods of drought.

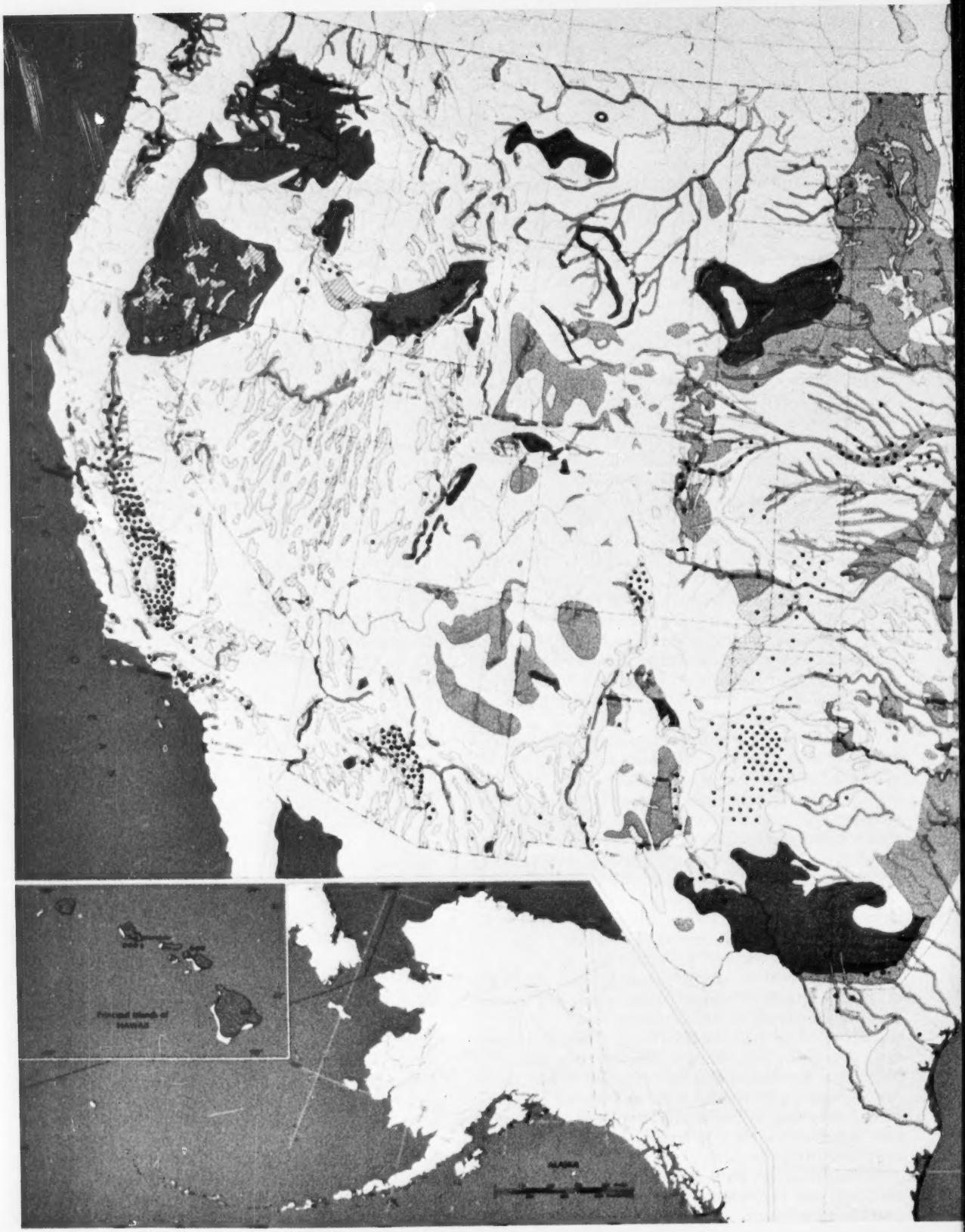
The Northern Great Plains study (which includes parts of Wyoming, Montana, North Dakota, and South Dakota) represents an expansion of an earlier study of the Madison limestone aquifer system. The concern in this area is whether deep ground water can be developed for mining operations, coal slurry pipelines, and power generation in a region where surface water and shallow aquifers are already committed to other needs.

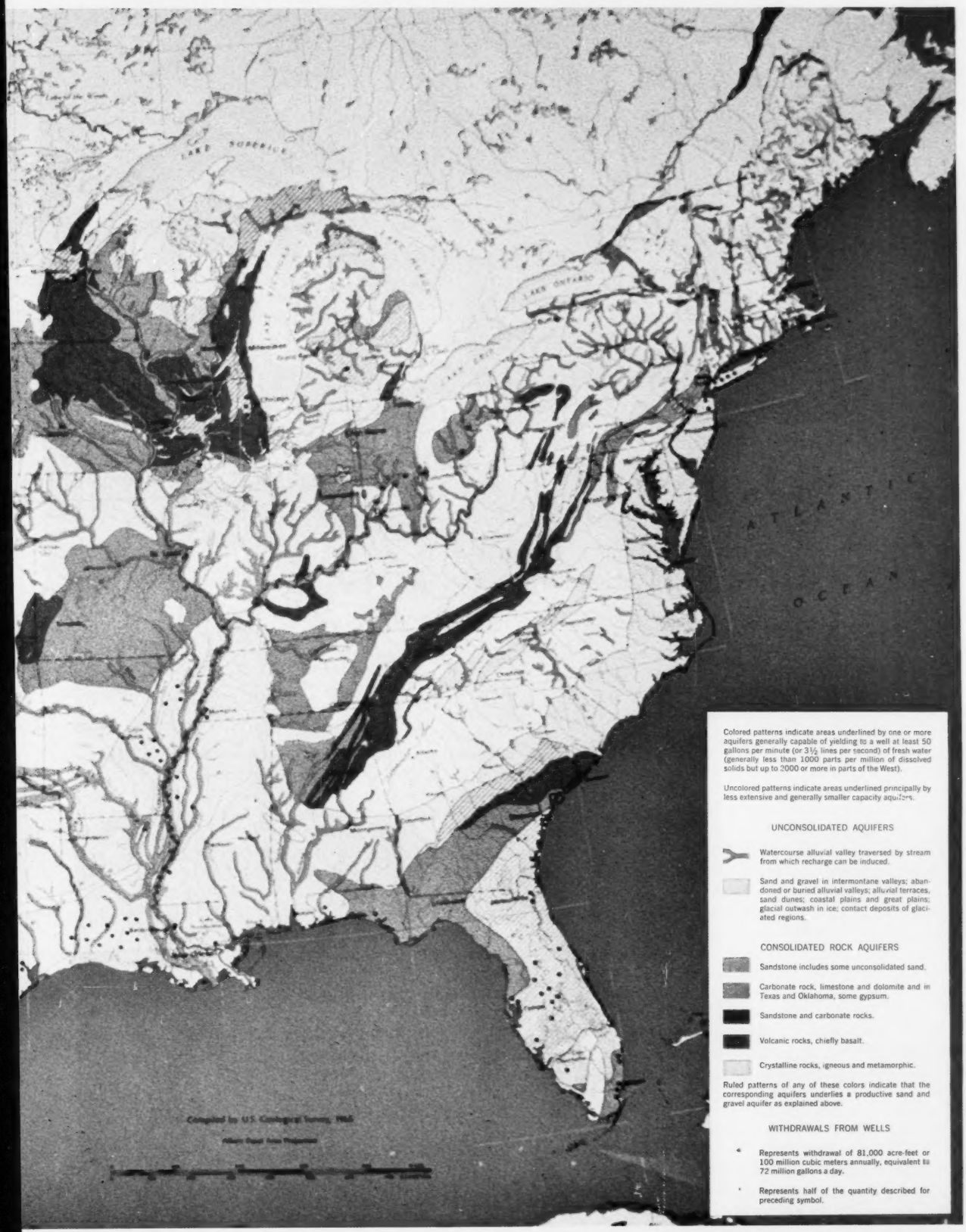
The High Plains project will expand and unify several ongoing U.S. Geological Survey studies of the Ogallala aquifer. For several decades, this aquifer has sustained the agricultural economy of parts of Kansas, Nebraska, South Dakota, Wyoming, Colorado, Oklahoma, New Mexico and Texas. Withdrawals have greatly exceeded recharge, and, at present rates of pumping, some parts of the area appear to face exhaustion of the resource before the end of the century. The study will attempt to simulate the hydrologic impacts of pumping and will be coordinated with an economic analysis commissioned by the Department of Commerce.

The southwest alluvial valleys (parts of Arizona, New Mexico and Texas) were chosen for study because of the heavy reliance of the region upon ground water and the increasing competition between irrigation and municipal use for the available supply. The water demands of cities such as Tucson, Phoenix, and Albuquerque have grown rapidly in recent years. In the El Paso area the problems take on an international character, with competition for ground water from both sides of the border.

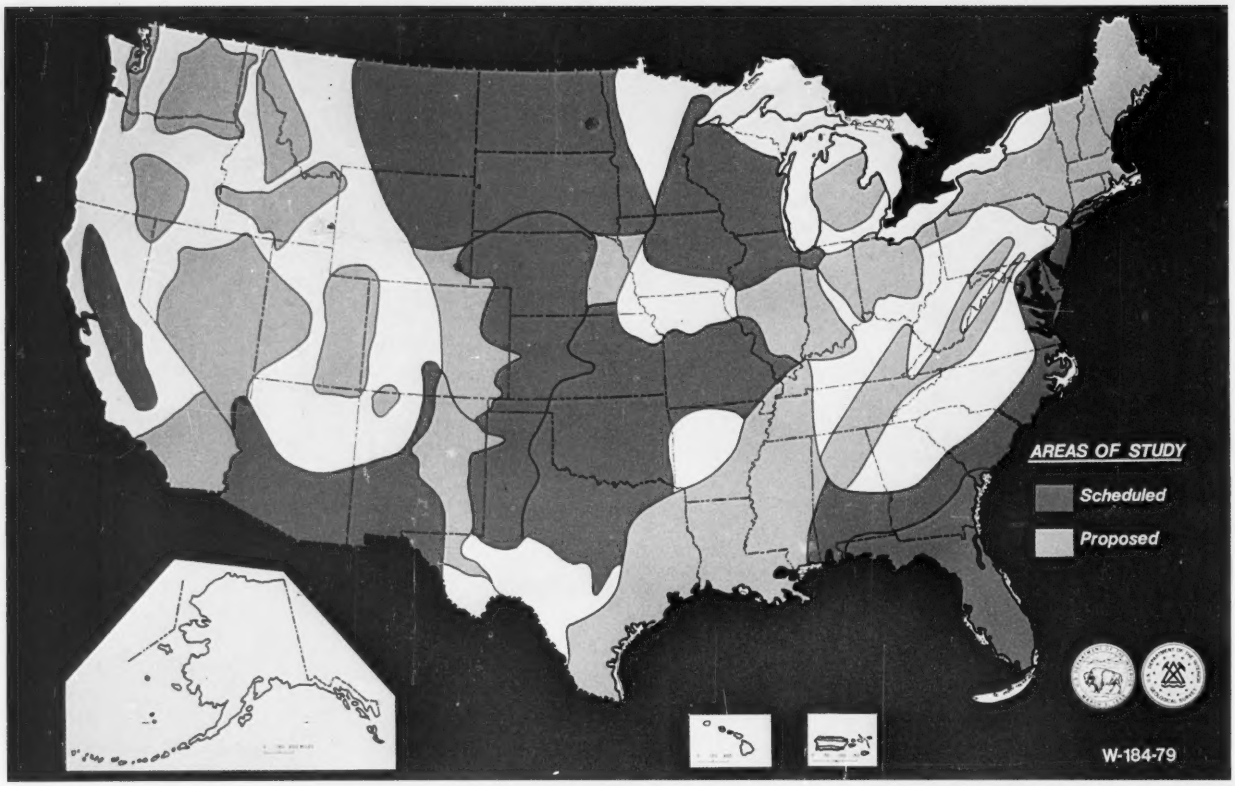
The southeastern carbonate aquifers form a major source of supply for all of Florida and eastern Georgia, and for small areas in Alabama and South Carolina. The study was undertaken because a rapidly growing population has placed heavy demands on the system throughout Florida, while pumpage for public and industrial supply has increased significantly in Georgia. In both states, increasing irrigation withdrawals represent a growing competitive use, and salt water intrusion in heavily pumped coastal areas is a perennial concern.

The sandstone aquifer system of the northern midwest forms a major source of supply for three large metropolitan areas—Chicago, Milwaukee, and Minneapolis-St. Paul—as well as for several smaller cities such as Madison, Green Bay, Des Moines, and Cedar Rapids. The separate areas of




ATLANTIC
OCEAN
Colored patterns indicate areas underlined by one or more aquifers generally capable of yielding to a well at least 50 gallons per minute (or 3½ lines per second) of fresh water (generally less than 1000 parts per million of dissolved solids but up to 2000 or more in parts of the West).
Uncolored patterns indicate areas underlined principally by less extensive and generally smaller capacity aquifers.
UNCONSOLIDATED AQUIFERS
Watercourse alluvial valley traversed by stream from which recharge can be induced.
Sand and gravel in intermontane valleys; abandoned or buried alluvial valleys; alluvial terraces, sand dunes; coastal plains and great plains; glacial outwash in ice; contact deposits of glaciated regions.
CONSOLIDATED ROCK AQUIFERS
Sandstone includes some unconsolidated sand.
Carbonate rock, limestone and dolomite and in Texas and Oklahoma, some gypsum.
Sandstone and carbonate rocks.
Volcanic rocks, chiefly basalt.
Crystalline rocks, igneous and metamorphic.
Ruled patterns of any of these colors indicate that the corresponding aquifers underlies a productive sand and gravel aquifer as explained above.
WITHDRAWALS FROM WELLS
Represents withdrawal of 81,000 acre-feet or 100 million cubic meters annually, equivalent to 72 million gallons a day.
Represents half of the quantity described for preceding symbol.

The major aquifers of the United States.



The Regional Aquifer-System Analysis study areas. The Snake River Plain will be added to the study in 1980.

declining ground water levels, caused by heavy pumping in Chicago and Milwaukee, have widened until they now form a single zone of depletion affecting the entire region between the two cities. Increasing irrigation constitutes a competing use of the aquifer.

The Atlantic Coastal Plains Project will study the unconsolidated aquifers along the Atlantic Coast from Long Island to North Carolina. This is a densely populated region with numerous water supply and waste disposal problems, and utilization of the aquifers is already heavy in many areas. Increasing drawdowns are becoming a problem around some pumping centers, and there is evidence of land subsidence and saline water encroachment in some localities.

The Southeast Coastal Plain Project will cover the unconsolidated sediments from South Carolina to Mississippi, in a belt following the northern limit of the Southeastern Carbonate Regional Study. Increasing irrigation is a major concern in this area. Moreover, there appears to be a high degree of interconnection between these aquifers and the Southeastern Carbonate aquifers. Study of the two systems on a concurrent basis will permit a realistic evaluation of their interaction.

The Snake River Plain of Idaho is underlain by prolific basalt and alluvial aquifers that are heavily pumped for irrigation. Discharge from these aquifers is an important component of the total flow of the Snake River. This study will focus on the development of models suitable for management purposes, and on the relationship between the freshwater system and underlying geothermal zones.

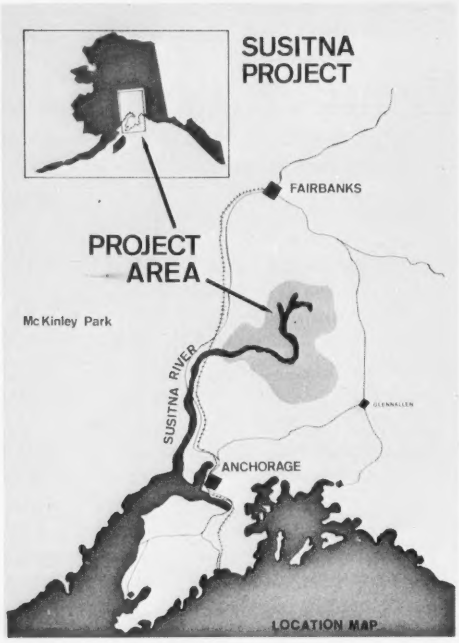
The Central Midwest Carbonate study will be concerned with the Arbuckle limestone and associated aquifers in Texas, Oklahoma, Arkansas and Kansas, and with the limestones of the Ozark region in southwestern Missouri. The Arbuckle and associated units contain a complex distribution of fresh and saline waters, and are widely used for both irrigation supply and waste disposal. The limestones of the Ozark region are some of the most prolific water producers of the country, and constitute a reservoir of great potential significance. The entire area of this study was severely affected by the drought of 1976-77, and there is widespread interest in ground water as a drought-resistant source for the future.

In summary, the Geological Survey's Regional Aquifer-System Analysis Program is designed to provide an understanding of existing ground water flow systems and water quality distributions on a regional scale, to provide predictive capabilities through which the consequences of development can be evaluated, again on a regional scale, and to provide a framework for more detailed local investigations. It is hoped that this information will form a basis for efficient management of the nation's ground water reserves, particularly during the rapidly expanding development which is foreseen over the next decade. ■

susitna survey: concern for the land

by
Weldon Opp & Allan Wylie

Watana damsite on the Upper Susitna River in Southcentral Alaska.



What could become one of the U.S. Army Corps of Engineers' largest civil works projects—a hydropower complex on the Upper Susitna River in Southcentral Alaska—is "on hold" despite its conditional authorization for advance engineering and design authorization by Congress in the Water Resources Development Act of 1976.

Top-level approval of a two-dam project with a transmission line serving Fairbanks and Anchorage—the development proposed in the Corps' Alaska District's feasibility report—is a big unknown at presstime. So is the matter of funding (either Federal or state) for detailed study. A complication has been the Alaska "D-2" Land Bills still under consideration by Congress, and the 1976 Federal Land Policy and Management (Organic) Act, both of which greatly influenced the District's 1978 supplemental geological exploration and related field activities.

This account describes the Alaska District's activities on the proposed Susitna River hydropower project during 1978 when it took to the field in the face of many challenges to gather supplemental data for the Office of Management and Budget (OMB) in furtherance of the project feasibility report. That 1975 report and accompanying environmental impact statement moved from the Chief of Engineers Office to OMB in May 1977, and recommended authorization for Phase I Advance Engineering and Design.

During its review, OMB decided that because of the magnitude of the 1975 estimate of project costs ($1.5 billion), verification of the cost estimate and benefit-cost status would be needed before the project could be recommended to Congress for proceeding to Phase I planning. Project costs are highly sensitive to site foundation conditions and to contingency factors used in cost estimating. It was determined that confidence in the project's feasibility and the cost estimates could be achieved with a season's field work in geological explorations and reevaluation of the supply and demand concepts. The added study would be directed at those aspects of feasibility to which the benefits and costs are most sensitive. The Alaska District was directed to develop the data and publish a supplemental report for OMB consideration.

To gain access to the Watana damsite (some 50 miles from the nearest maintained road) to conduct foundation explorations, Federal land had to be crossed. This put the District on the doorstep of the "landlord" of the area, the

---

Mr. Opp is the Chief of Planning, Alaska District, U.S. Army Corps of Engineers. Major Wylie was his assistant on the Susitna Project.

Bureau of Land Management (BLM). The Secretary of the Interior was under Congressional direction to conduct a wilderness study as outlined in Section 603 of the Organic Act. This study required that BLM inventory the natural resources in all roadless areas of 5000 acres or more in territory under their jurisdiction. In Alaska this meant they had the responsibility to study more than 200 million acres, an expanse equal to the combined acreage of Texas and Pennsylvania.

In order for any of those areas under consideration to be recommended to Congress for wilderness classification they must meet certain characteristics described in the 1964 Wilderness Act. Steps therefore had to be taken to insure that undue or unnecessary degradation of the lands and their resources would not take place, and to provide environmental protection where necessary to preserve the wilderness characteristics.

It was this situation that had the Alaska District on the outside looking in, as it were. However, both agencies have concern for protection of the environment and it was this mutual concern that produced remarkable cooperation and teamwork that got the job done and preserved the pristine wilderness on the Upper Susitna River.

Shortly before Corps' meetings with BLM on these matters, the Secretary had recommended an amendment to Representative Morris Udall's 1978 Bill, HR 39, that would establish and set aside some 110 million acres of lands for national parks, wildlife refuges, and wilderness areas; and several streams for wild and scenic river designation. If adopted, the recommended amendment would require the Susitna River be studied as a possible wild and scenic river.

Action on that recommendation was uncertain, so it became advisable to study the feasibility of water resource development in the Alaska District's interest area so that information would be available to help Congress decide the best use of the Susitna River. In effect, the District study would produce information that might be helpful to BLM.

The resource values of a wild and scenic river are its free-flowing character, water quality, and line-of-sight aesthetics. With proper safeguards and extreme care exercised by both BLM and Corps' representatives monitoring field work, any damage associated with Corps' operations would be only short term.

Pallets of fuel drums being air-dropped into Watana site. (CofE Photos)

An environmental assessment was prepared that evaluated and addressed the proposed exploration activities at the two damsites.

Most of the work at the Watana site would be: (1) core drilling at the abutments, underground

facilities, and river foundation to verify the quality of rock and the existence or absence of serious faulting in the channel; (2) probing the area of the saddle spillway to check the extent of an old buried channel and exact bedrock location; and (3) verifying local quantities and qualities of earth and rock suitable for dam embankment construction. Explorations at Devil Canyon would concentrate on materials availability.

Two public meetings were conducted jointly with BLM to obtain public reaction to the proposed explorations. Comments varied from "the activities would endanger wildlife, and if the dam is built it could end up collapsing in an earthquake," to "the electrical energy is needed and the sooner construction begins, the better."

The initial plan for operations on the Susitna envisioned construction of two camps, one at each site, to house field teams. That was abandoned in favor of having the crew based in Talkeetna and helicoptering to and from the sites, 60 miles away. On per diem, the workers arranged for meals and motel rooms in this little settlement, which is an internationally known mecca for climbers as the starting point for assaults on Mount McKinley. As well as being less costly than setting up camp for one season, this method of housing and transportation eliminated the need to build service roads and gravel pads, and only local tree cutting for safe landing spots became necessary. When ice disappeared, floatplanes could operate on small lakes within walking distance of the Watana damsite.

Cat train approaching Watana site.

With these housekeeping matters out of the way, the Corps' cooperative agreement with BLM on environmental protection procedures became simpler. The main issues then were: (1) survey of the area for possible archeological resources; (2) consultation with U.S. Fish and Wildlife Service to assess presence of endangered and threatened species; and (3) the exact means and methods of protecting the landscape so as not to degrade it to the point of negating its potential wilderness classification.

Safeguards were spelled out in 18 stipulations in precise terms that would ensure the conduct of geological investigation under strict environmental protection rules. It was agreed to be essential that overland movement of equipment needed on site would be carried out over snow and frozen ground to avoid leaving lasting evidence of travel and damage to the soil and vegetation. The stipulations also addressed protection of streams and water quality, fish and wildlife and their critical habitat, solid waste disposal, inter-site travel modes, and rehabilitation measures.

Records of sightings of the endangered peregrine falcon, subspecies *Falco peregrinus anatum* (American) and *Falco peregrinus tundrium* (Arctic), when they migrated through the river basin, led to establishment of a monitoring system within the project area and on related air traffic routes by a Fish and Wildlife Service raptor expert. On two separate week-long vigils, no sightings were made in areas previously recorded, but to assure no harassment, all flights would be at least 1000 feet above the ground. If sightings had been confirmed, field activities would have ceased until their impact on the birds could be evaluated.

An archeologist was engaged to determine the likelihood of finding locales of potential archeological significance within the general exploration site. Because very little ethnographic material exists concerning the Susitna River Basin, and no archeologist had studied the area, the task of predicting site occurrences was very difficult. To protect possible existing cultural resources, a two-phase survey of these areas was conducted. The Phase I survey identified locales likely to contain archeological materials, and projected the probable courses of exploration as they might impact on those locales. Then, with maps showing locations of proposed drilling and excavations, an archeologist made an aerial reconnaissance to become generally familiar with the area even while the ground was covered with snow and still frozen.

The Phase II survey was made in June and in August, when surface investigations were conducted. Natural exposures of windblown and eroded areas were inspected and the tops of small hills and knolls were examined to determine evidence of prior human existence. Small test excavations were made, as necessary, to provide more complete coverage.

Although the effort was fast-moving, the archeologist's trowel encountered definite evidence of prehistoric man's presence in the area. Four sites dating to prehistoric times were found on tops of knolls. They proved to be the first to be reported in the area, and thus were significant finds. Stone flakes and one stone tool that were recovered were contributed to the University of

Alaska's museum in Fairbanks. The tool is a triangular blade exhibiting a ground concave base 1.7 centimeters in width and flaked on both sides for a length of 3 centimeters. As a result of the finds, all travel routes of ground equipment were restricted to side slopes and swales.

Selection of suitable vehicles to be used in the river basin was thoroughly discussed in the District-BLM meetings. Valuable background information existed which pointed to the solution. Experience gained during Navy petroleum exploration on the Arctic tundra beginning in 1949, the activities associated with DEW-Line construction in the late fifties, and recent North Slope oil activities, all demonstrated that lightweight, low-pressure vehicles do not generally cause long lasting surface disturbances. The agreement with BLM specified that all land vehicles have low ground pressure tracks, or tires exerting less than 3.5 pounds pressure per square inch. Also, at time of mobilization there had to be at least a foot of snow and six inches of frozen material on which to move in the roadless area en route to Watana so as to avoid vegetation damage. In the vicinity of the damsites, vegetation ranges from spruce trees dominated by boreal forests in the water course valleys, to alpine shrub tundra at slightly higher levels. Much of the approach route to Watana would be over rolling country marked by tundra and low tree growth. It was both agencies' concern and intent to minimize man's imprint on all growing things.

In order to get all field work done in one short season, the first priority of exploration was to obtain rock cores of the foundation site in the river by drilling through its frozen surface. To meet this target, drilling had to start by mid-March.

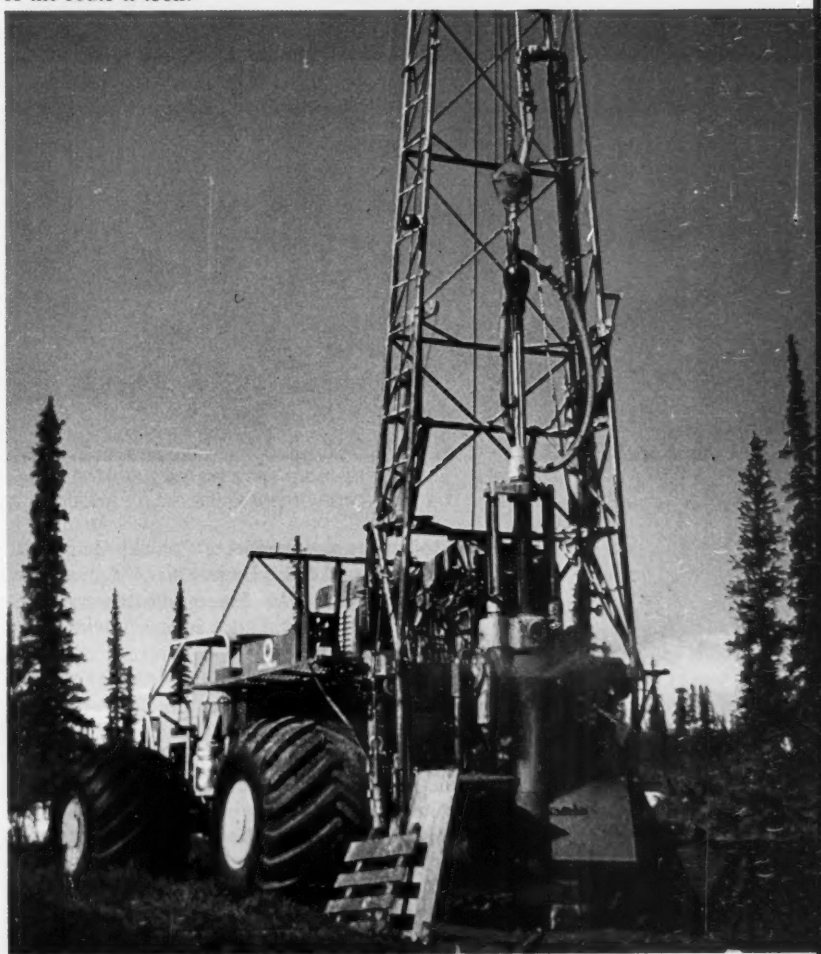
Equipment had to be moved 50 miles cross country from the Denali Highway to the Watana damsite. A cat train was formed consisting of wide tundra track D-7 cats, Nodwells, and a Bombardier pulling sleds carrying drill equipment, timber, and some fuel and other gear. The train was guided by specially designated Corps and BLM representatives serving as trail monitors. They scouted ahead on snow-machines, picking the best route, receiving radio guidance from a helicopter from which distant views over rises were possible. This procedure enabled the train to reach the work site safely and with minimal disturbance to the terrain.

A 45-foot house trailer was pulled to the site by a D-7 cat to serve as quarters during the tundra trip and as a communications point and emergency shelter at the work site. On one occasion the shelter became a refuge for eight weary, wet soldier canoeists who tried Susitna's dangerous waters, got swamped, lost a canoe and equipment, and found themselves cold, hungry, and stranded in the wilds. The radio was used to call an Army chopper to take them back to Fort Wainwright after they were fed and warmed.

When the cat train was near Watana, a helicopter lifted off two drills, fuel, generator, floodlights, some lumber, and a portable "john," taking them down into the river canyon for the ice operation. As soon as a drill and its protective wooden enclosure were in place, drilling commenced. Two crews operated around the clock to put down four holes before the ice went out. Crews included drillers from the Corps' Portland and Mobile Districts, plus two geologists from the Portland District.

Drills chewed through 4 to 5 feet of ice, 6 to 10 feet of water, plus 50 to 100 feet of gravel and other loose sediment before reaching bedrock. Cores about 100 feet long were pulled from the rock and sent out for lab testing.

A second test train brought in a large drill mounted on a swamp buggy that was a loan from the Corps' exploration pool at Mobile. The 4-foot wide, 5-foot diameter, rubber-tired vehicle worked extremely well: it left only a brief trace of the route it took.

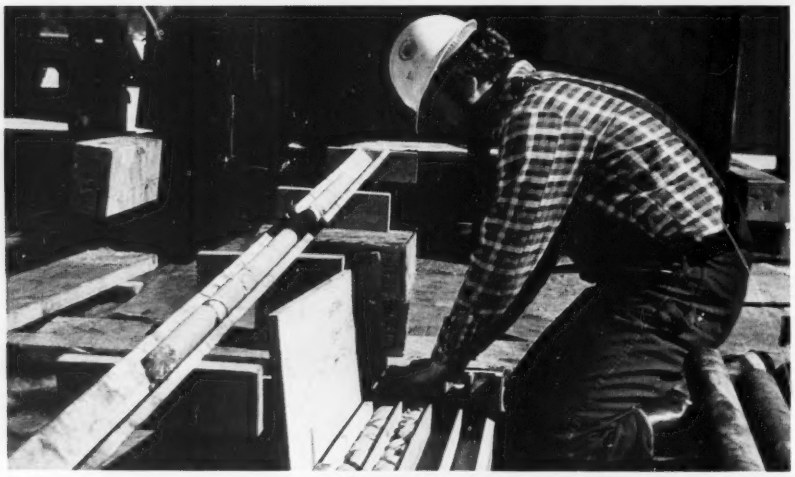


Swamp buggy-mounted drill on terrace above Susitna River.

After drilling on the ice was completed (just about the time the ice broke up early in May), the equipment was air lifted to the abutment areas on the canyon sides. The aerial system was used also in all support of personnel, including delivery of water in 300-gallon tubs. All waste material and empty drums were back-hauled by chopper to Talkeetna for trucking to Anchorage. In all, 1200 hours of helicopter flight time were logged during the operation.

Only three passes over the trail were allowed under the agreement, this being sufficient to put workers and equipment on the scene to start drilling through the ice. Had it not been for air drops of additional cargo, eight more round trips of surface vehicles would have been necessary to complete the work. That many more trips posed a threat of unacceptable landscape damage, so aerial movements had to be the solution. As it turned out, only two of the three permitted surface trips were run.

Recognizing the need to avoid permanently scarring the tundra and virgin wilderness, the



Some of the core samples from Watana are packed for shipment to the lab for testing.

Alaska District Engineer, Colonel George R. Robertson, asked his Deputy, Lt. Col. Jim Fero, to approach the Air Force with the problem. A commercial-rated plot himself, with paratrooper experience, he was an excellent liaison for talks with the 616th Military Airlift Group on Elmendorf AFB about the possibility of their air-dropping materials at Watana. "Dropping" the cargo to the work area would not only make the additional cat train trips unnecessary, it would enhance the likelihood of completing the entire mission within the brief exploration period available.

A side benefit that interested BLM in this regard was that fewer snow trails left by the District's cat trains would lessen the likelihood that summer-time recreational all-terrain-vehicles would have traces to follow in an area that was under consideration for wilderness classification.

The 616th liked the idea of carrying out "real" paradrops in a remote area; it would be much better training than the simulated missions they had been running—dropping palletized sandbags in familiar established drop zones. The 616th MAG's Combat Control Team (CCT), which establishes drop zones and provides ground control for the deliveries, had only one member with experience beyond the simulated exercises. They looked forward to the Susitna project.

Under the District's proposal, the MAG would set up the remote target and missions to drop Corps' equipment and supplies on a firm operation schedule. They would develop a live mission scenario that would test and evaluate their capability and skills. The Alaskan Air Command and the Military Airlift Command monitored the training for readiness evaluation of the Group during their missions. Both commands reported favorably on the unit's readiness and training.

Archeologists found evidence of prehistoric man at four sites in the Watana area.

Two M-116 tracked personnel carriers were on long-term loan from the Alaska Army National Guard, for the assembly of 600 barrels of fuel needed at Watana. All had to be rigged for parachute deliveries that would be made over a period of several weeks. They had to be spotted on the base loading ramps in accord with a tight mission schedule.

Being short of parachute riggers, the District sought help from the 172d Infantry Brigade (Alaska) at nearby Fort Richardson. Its rigging section, like the MAG flight crews and CCT, was pleased to be involved, and to be preparing actual cargo for live drops to targets in the wilderness.

A typical drop consisted of three to five C-130 "Hercules" aircraft loads of supplies operating against a time-on-target of 6 a.m. This called for District members to make the initial pick-up of loads at Fort Richardson at 1:30 a.m., completing delivery to the Elmendorf ramp by 3 a.m.

The "go", "no-go" decision rested with the Alaska District until the loaded C-130s were under the control of the CCT. Thus, the Corps had to stick closely to the rigging phase and ramp delivery, and have complete weather watches during the preceding 24 hours, and in particular up to the point of aircraft take-off. When one loaded flight had to abort because of foul weather, everything had to be retrograded and the cargo taken back to the post for temporary storage. The mission decision had to be early and right, therefore, to avoid massive extra work.

What started out as an improved training exercise for the 616th MAG turned out to be a valuable experience for everyone involved in this multi-service endeavor. In retrospect it is difficult to judge who derived the most benefit because: (1) several MAG pilots gained extra training in dropping "live" non-standard loads. Their CCT became more proficient in establishing themselves in unfamiliar terrain under actual operating conditions in the Alaskan winter; (2) the Brigade's hard-working riggers learned what volume and quality of work they could produce under pressure; and (3) the District gained valuable time in its exploration program through air-dropping supplies and simultaneously avoiding undue environmental damage. The drops of vehicles and fuel were so satisfactory that air-drops of an additional 25 tons of drill steel and associated equipment were added. Seeing a 5-ton tracked personnel carrier floating to the snow-blanketed earth under a trio of 100-foot diameter parachutes, and settling safely with a neat soft bump was most impressive; the product of military professionalism. No fuel spills; no damaged vehicles.

Through this operation also, BLM learned that 360 barrels of fuel (scaled down from 600 because of reduced needs in the field), two military vehicles, and tons of supplies could be delivered to a spot in the wilderness with virtually no terrain damage.

Illustrative of the environmental care with which the program was managed, throughout the spring and summer the two designated representatives (District and BLM), and the Corps' environmental monitor, watched over compliance with the stipulations and even consulted and agreed on locations of all drill and excavation sites and access routes before allowing any equipment to move. They required that anywhere overland movement of drilling or support equipment was needed, a sinuous route would be used to protect the aesthetic view and avoid creating straight-line surface disturbance patterns. They ensured that test pits that were dug for material samples were refilled and contoured, and they agreed on any required rehabilitation efforts upon leaving each site. Rehabilitation work was verified and recorded on a check sheet signed by both parties. One of the stipulations they oversaw required drill tailings to be spread out in a layer less than two inches thick. The bear, moose, caribou, and other creatures of the basin will encounter little evidence of human presence in their domain.

Looking downstream on the Susitna during winter, over-ice drilling operations.

Early this March, a year after the equipment was taken in, demobilization began. Three of the heaviest vehicles were dug out of the snow and dewinterized for their trip back across snow up to 12 feet deep. Aside from breaking through the lake ice at 10°F, fighting winds so fierce that walking was nearly impossible, throwing Nod-

Summer trace of cat train route.

well tracks, dropping a wrench into a gear box, white-out conditions that made flying extremely difficult, and being caught in the worst storm of the season when only a mile from Denali Highway, everything went fine.

The three pieces making the trip, the D-7 cat, Nodwell and rubber-tired swamp buggy, moved in file, fastened to each other with cables for safety and feeling their way back across the snow-covered tundra. The rest of the equipment at Watana, except the house trailer, was air-lifted by helicopter to the highway for trailering to Anchorage this summer. The emergency shelter house is being left on site for the time being for the convenience of BLM teams engaged in their field operations.

The supplemental report completed in February 1979 has been transmitted to OMB. It verifies by exploration, by examination of some 4900 feet of drill holes, by the testing of borrow materials, and the study of several seismic lines, that the Watana damsite is more geologically favorable than first judged on the basis of prior existing surface and seismic information. In the update study, the cost of the project did increase from the 1975 estimate of $1.5 billion to $2.3 billion, but with the re-analysis of the coal alternative and associated benefits the all-important benefit-to-cost ratio was calculated at $1.40 to $1.00.

When OMB releases the report, and after the final impact statement is filed with EPA for 30 days, the District could use the $5.4 million appropriated by Congress for the Alaska Hydroelectric Development Fund. The authorization included in the Water Resource Development Act of 1976 established that fund and permitted a joint partnership in which the state could fund construction of hydropower facilities, with the Corps as construction agent for the Federal Government. Thus, the state would become ultimate owner, with the U.S. Government providing construction expertise and guarantee of design and cost over-runs. This is a concept that goes even beyond the President's 1978 cost-sharing proposal presented for water resource development projects. ■

Events, Deeds & Deliberations

Ground Water May Aid Alaska Development

Large untapped and virtually unexplored ground water resources could play a significant role in the future development of Alaska, according to a new U.S. Geological Survey, Department of the Interior, report.

The USGS report says that the potential for ground water development far exceeds current use in areas of the state not affected by permafrost (perennially frozen ground) that severely restricts ground water availability in northern Alaska. For a rough comparison, the report notes that the average discharge from ground water reservoirs to streams is about 100 billion gallons per day, while ground water use was only 50 million gallons per day in 1975. Large amounts of ground water are stored in alluvium and glacial outwash deposits that underlie coastal basins and valleys.

Although Alaska has enormous surface water resources, many streams are frozen for much of the year and most contain glacial silt that makes them unacceptable for human use.

"The ground water resource," the report said, "presents both an opportunity and a challenge: an opportunity to circumvent many of the problems involved in the use of surface water, and a challenge to deal with ground water development problems such as local water-level declines, depletion of streamflow, saltwater intrusion, and ground water pollution. All of these are significant problems at some places and are potential problems at others."

A major factor limiting ground water development in Alaska is the need for much additional ground water information. The report recommends that collection of basic data and investigations of ground water hydrology in the state be intensified.

Copies of the report, "Summary Appraisals of the Nation's Ground Water Resources—Alaska," by Chester Zenone and Gary Anderson, published as USGS Professional Paper 813-P, may be purchased for $1.60 each from the Branch of Distribution, USGS, 1200 South Eads St., Arlington, VA 22202. Orders must include check or money order payable to the U.S. Geological Survey. Copies also may be purchased over the counter only from the Public Inquiries Office, USGS, 108 Skyline Bldg., 508 Second Ave., Anchorage, Alaska. ■

Interior To Attack Desertification

The Department of the Interior's Bureau of Land Management will have a leading role in the development of a national plan to prevent further spread of deserts in the United States, Under Secretary James Joseph has announced.

Joseph said the BLM, which manages vast expanses of arid land in the West, will cooperate with all appropriate Federal and international agencies in developing and coordinating efforts to combat desertification.

Desertification is the result of both natural and man-made conditions that lead to the formation of deserts and creation of desert-like conditions.

"Deserts cover about ⅓ of the land surface of the world," Joseph said. "We know that once much of the present desert areas were green and productive. For example, the deserts of our southwest once supported thriving communities of a people we call Anasazi. Prolonged drought, along with other factors, forced the Anasazi to leave the area. Deserts are spreading even today. The vast Sahara Desert of North Africa covers an area larger than the United States and sand dunes are slowly encroaching onto adjoining lands at a rate of 60 to 700 feet per year.

"Misuse and abuse of arid lands causes them to deteriorate to desert conditions. Desertification and drought are man's most bitter enemies and pose a grave threat to the growth of many developing countries."

Joseph said he expected the plan to be finished in 12 months. ■

New Technique Tracks Sewage Dumped At Sea

National Oceanic and Atmospheric Administration (NOAA) scientists have identified a biochemical technique that can be used to trace sewage in coastal areas, a matter of vital interest to environmental managers in heavily populated parts of the coast. The newly identified technique uses coprostanol, a steroid thought to be produced exclusively by bacteria in the intestines of mammals, to measure sewage in offshore sediments.

According to NOAA's Atlantic Oceanographic and Meteorological Laboratories in Miami, the coprostanol method promises to become the standard for sewage-pollution detection. The lab developed the technique as part of a major ecosystem study NOAA has conducted in the New York Bight, the 15,000-square-mile continental shelf area off the New York-New Jersey coast.

Because sewage sludge, the end product of waste-water treatment, is dumped in the Bight, scientists and citizens are concerned about sewage contamination there. But sewage is difficult to trace in the chemically complex marine environment. The Commerce Department researchers turned to steroids—biochemical compounds that resist deterioration in the environment. The steroid coprostanol was found to be present in contaminated marine sediments, but not in uncontaminated sediments, and appeared to be stable enough to be used as a tracer of sewage. Subsequent work led to a "percent-coprostanol" term that permits the scientists to estimate how much of a sample's organic matter is sewage-derived.

With the technique, a map of the New York Bight has been developed showing sewage pollution centered in a basin near the sewage-sludge dump site, and diminishing rapidly with distance away from the dump site. The highest value found was 15 percent coprostanol in the highly contaminated black muds near the dump site. Pure sewage contains more than 30 percent. (*Marine Fisheries Review*) ■

Coming Events

Water Pollution Control Federation Conference, Houston, Texas, October 7-12.

Coastal Society's Fifth Annual Meeting, entitled "Resource Allocation Issues in the Coastal Environment," Newport, R.I., November 7-8.

International Symposium on Drought, New Delhi, India, December 2-7.

International Symposium on the Hydrology of Areas of Low Precipitation, Canberra, Australia, December 10-13.

Bookshelf

"The Nation's Water Resources 1975-2000," the Second National Water Assessment by the U. S. Water Resources Council, is an excellent report that provides considerable data useful to water resource development planners and practitioners. It is available from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402 for $3.25. Stock Number 052-045-000510-7.

Can Organizations Change: Environmental Protection, Citizen Participation, and the Corps of Engineers, by Mazmanian and Nienaber, states in its foreword that "The Army Corps of Engineers seems to be making a concerted effort to comply with both the spirit and the letter of the law, calling for greater public involvement and environmental awareness in the decision-making process."

SUBSCRIPTION ORDER FORM

ENTER MY SUBSCRIPTION TO *Water Spectrum* (WASP)

☐ $5.50 for one year

Add $1.40 per year for foreign mailing.

(No additional postage is required for mailing within the United States, its possessions, Canada, Mexico, and all Central and South American Countries except Argentina, Brazil, British Honduras, French Guiana, Guyana, and Surinam. For shipment to all other foreign countries include additional postage as quoted.)

Send Subscription to: **Please Print**

NAME—FIRST, LAST

ORGANIZATION OR ADDITIONAL ADDRESS LINE

STREET ADDRESS

CITY STATE ZIP CODE

☐ Remittance Enclosed (Make checks payable to Superintendent of Documents)

☐ Charge to my Deposit Account No. .....

MAIL ORDER FORM TO:
Superintendent of Documents,
Government Printing Office,
Washington, D.C. 20402

The authors use five case studies of Corps' projects to demonstrate how the Corps' "apparently atypical response" to demands for change affected its missions, organizational structure, planning and field activities. Available in hardcover from the Brookings Institution, 1775 Massachusetts Avenue, N.W., Washington, D.C. 20036, at $11.95. 220 pages.

Toward a Solar Civilization by Robert H. Williams, portrays solar energy as a very major resource. It considers the present economic limitations of solar energy, but offers thoughts on how to overcome development obstacles. Electricity, fuels, and third world development are among the numerous topics discussed by the book's contributed papers.

The book is available from the MIT Press, 28 Carleton St., Cambridge, MA 02142 for $12.50, hardcover.

Changes of Command

Major General James A. Johnson has been named as the Deputy Chief of the U.S. Army Corps of Engineers. He assumed that office in June and succeeded Major General Bates C. Burnell, who retired after 34 years of military service. Gen. Johnson had been serving as Division Engineer, North Atlantic Division of the Corps in New York City. In his new capacity, he will be the principal assistant and advisor to Chief of Engineers Lieutenant General John W. Morris, on both the military and civil works activities of the Corps.

Replacing Gen. Johnson in the North Atlantic Division is Major General Bennett L. Lewis. He was assigned to that post in July, from previous duty as Commander, U.S. Army Armament Research and Development Command, Dover, N.J.

Major General E. R. Heiberg III had just been named the new Director of Civil Works for the Corps of Engineers, at press time. He replaces Maj. Gen. Charles I. McGinnis, who has retired.

Brigadier General Henry J. Hatch is the new Pacific Ocean Division Engineer, with duty station in Honolulu. He has replaced Brig. Gen. Maurice D. Roush, who has retired. Gen. Hatch was most recently assigned to the U.S. Army Engineer School at Fort Belvoir, Virginia.

Colonel Max B. Scheider has assumed duties as the New England Division Engineer in Waltham, Massachusetts. The former deputy division engineer, Scheider replaces Col. John P. Chandler, who has retired.

Colonel Ted E. Bishop assumed command of the U.S. Army Coastal Engineering Research Center at Fort Belvoir, replacing Col. John H. Cousins who has retired. Bishop was previously with the Planning Division, Civil Works Directorate, Office of the Chief of Engineers.

Colonel William H. Reno became the Memphis District Engineer in June. He replaced Col. Robert W. Lockridge. Col. Reno had attended the Army War College at Carlisle Barracks, Pennsylvania prior to the Memphis assignment.

Colonel George P. Johnson has been named Buffalo District Engineer, replacing Col. Daniel D. Ludwig, who has been reassigned as deputy division engineer, Middle East Division (Rear). Johnson was most recently with the Office of the Chief of Staff, U.S. Army.

Colonel Donald J. Palladino has become the Fort Worth District Engineer, and replaces Col. John F. Wall, Jr., who has been reassigned to the Office of the Chief of Engineers in Washington. Col. Palladino had been deputy division engineer, Middle East Division.

In a July reassignment, Colonel Nelson P. Conover took over as Director, U.S. Army Waterways Experiment Station, Vicksburg, Mississippi. He replaced Col. John L. Cannon, who becomes the deputy division engineer, Lower Mississippi Valley Division, also in Vicksburg.

Also in July, Colonel Samuel P. Collins became District Engineer in Vicksburg. He replaced Col. John H. Moellering, who has moved to Washington as executive officer to the new Army Chief of Staff designate. Collins had most recently been an assistant director of Civil Works, Office of the Chief of Engineers.

Colonel Paul F. Kavanaugh was named Sacramento District Engineer in August, replacing Col. Donald M. O'Shei. Col. Kavanaugh had been serving with the U.S. Army Training and Doctrine Command, Fort Monroe, Virginia.

Colonel Henry J. Thayer became Walla Walla District Engineer in August, succeeding Colonel Christopher J. Allaire. Thayer had most recently been Chief of the Facilities Engineering Division at the U.S. Army Training and Doctrine Command, Fort Monroe, Virginia. Allaire has been assigned to Fort Lewis, Washington, as Facilities Engineer.

Colonel Robert J. Dacey became St. Louis District Engineer in August, replacing Colonel Leon E. McKinney. Dacey has been assigned since 1977 with the Office of the Deputy Chief of Staff, Operations and Plans, at the headquarters of U.S. Army, Europe and Seventh Army in West Germany.

Colonel Robert V. Vermillion became Detroit District Engineer in August. He replaces Colonel Melvyn D. Remus, who has been reassigned to Europe. Vermillion was serving as chief of Management Division, Office of the Deputy Chief of Staff, Engineer, at the headquarters of U.S. Army, Europe, in Heidelberg, West Germany.

Lieutenant Colonel Leon K. Moraski assumed duties as Seattle District Engineer in July. He succeeded Colonel John A. Poteat, Jr., whose new assignment was not immediately announced. Moraski had been serving as Executive Director to the Commanding General of the U.S. Army Materiel Development and Readiness Command in Virginia.

The U.S. Army Corps of Engineers Water Resources Support Center has been established at Fort Belvoir, Virginia. The Center will organize, manage and perform studies and analyses for meeting regional, multi-regional and national water resources objectives as well as other consultive services in the areas of water resources management and development. It will also publish *Water Spectrum*. ■

WRSC-B
DEPARTMENT OF THE ARMY
U.S. ARMY CORPS OF ENGINEERS
WATER RESOURCES SUPPORT CENTER
FT. BELVOIR, VA 22060

OFFICIAL BUSINESS

POSTAGE AND FEES PAID
DEPARTMENT OF THE ARMY
DoD-314

U.S.MAIL

CONTROLLED CIRCULATION RATE

ADDRESS CORRECTION REQUESTED
Forwarding and Return Postage Guaranteed

WASP UNIVE300UDISSDUE000R 1
UNIVERISTY MICROFILMS
SERIALS PROCESSING
300 N ZEEB RD
ANN ARBOR MI 48106

Prehistoric habitation preservation was but one manifestation of the environmental caution exercised during Alaska Hydropower Project field work in the Susitna River Wilderness. See "Susitna Survey: Concern For The Land" on Page 43.